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Inventory of nearshore fish population densities and community structures at Apostle Islands National Lakeshore and Isle Royale National Park

Owen T. Gorman and Seth A. Moore

USGS Great Lakes Science Center
Lake Superior Biological Station
Ashland, Wisconsin

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ABSTRACT

Fish communities of the nearshore waters of the Apostle Islands National Lakeshore (APIS) and Isle Royale National Park (ISRO) were studied during the summers of 2003-2004. Objectives of our study were: 1) conduct an inventory of fish species to estimate relative abundances, describe community structures, and identify distribution patterns related to habitat associations, 2) compare nearshore and offshore fish communities in APIS, 3) evaluate the efficacy of various gear to sample fish communities, and 4) provide recommendations for establishing a long-term monitoring and research program. We found the nearshore fish communities of APIS and ISRO to be dominated by a set of common native species, which included lake chub (*Couesius plumbeus*), ninespine stickleback (*Pungitius pungitius*), slimy sculpin (*Cottus cognatus*), burbot (*Lota lota*), and trout-perch (*Percopsis omiscomaycus*). The predominant nearshore aquatic habitat of the APIS region was characterized by low slope with sandy substrates while in ISRO was characterized by moderate to steep slopes with coarse and bedrock substrates. Most of the shoreline of APIS and ISRO was exposed to the open lake, but embayments in ISRO provided protected habitat, particularly at the head of bays. Habitat in these protected areas was characterized by low slope, fine substrates and low structure, but harbored relatively diverse fish assemblages with high relative abundances. Species indicative of these protected habitats included spottail shiner (*Notropis hudsonius*), blacknose dace (*Rhinichthys atratulus*), and white sucker (*Catostomus commersoni*). Unprotected areas at the mouth of bays were characterized by high slope, rocky substrates and high structure, but harbored simple assemblages dominated by lake chub. In contrast, nearshore habitat in APIS with high slope and coarse substrates harbored more diverse fish assemblages than areas of low slope and fine substrates. The offshore fish community in APIS was dominated by coregonids and distinct from the nearshore community; only slimy sculpin held a position of strong importance in both communities. At a regional scale, the similarity in composition of nearshore fish communities of APIS and ISRO suggests that the fish communities of the nearshore waters of Lake Superior are drawn from a common source pool and that differences in habitat characteristics and protection from the open lake determine the local composition and structure of those communities. The lake chub was the most distinctive feature of the nearshore fish community as it was both unique to nearshore waters and was an abundant, conspicuous member of that community. Of four gears used to sample nearshore fish communities (seines, bottom trawls, Windermere traps, fyke nets) only Windermere traps sampled fish over the full range of nearshore habitats in both APIS and ISRO. For long-term monitoring of nearshore fish communities of APIS and ISRO we recommend using Windermere traps supplemented by fyke nets and electrofishing at intervals of 1-2 years. Future research in nearshore waters should address the linkage between nearshore fish communities and that of the open lake, particularly in regard to habitat and life history associations of nearshore and offshore species, spawning and nursery areas for open water fishes, and trophic and energetic contributions of nearshore waters to the Lake Superior ecosystem.

INTRODUCTION

To our knowledge, there are no published studies on the fish communities of the nearshore aquatic zone of Lake Superior proper. The diversity and complexity of nearshore aquatic habitats are likely to support a higher diversity of fishes than are found in the offshore zone of the lake (Hoff and Bronte 1999). The most comprehensive account to date of fishes of the nearshore zone of Lake Superior is included in a monograph on the fishes of Isle Royale by Hubbs and Lagler (1949). Although this monograph concentrates on inland waters of Isle Royale, it provides a compilation of fish records for the nearshore zone during 1904-1945. As such, the work of Hubbs and Lagler (1949) establishes a baseline for all future inventories of nearshore fish communities of Lake Superior.

In recent years, the National Park Service has expressed interest in acquiring information on the status of fish communities of the nearshore zone, as conservation of this habitat and its biological communities falls under agency jurisdiction: park boundaries extend into Lake Superior 0.25 mile around the Apostle Islands and 4.5 miles around Isle Royale. Assessment of nearshore fish communities in Lake Superior was identified as a high priority information need by the Apostle Islands National Lakeshore (APIS), Isle Royale National Park (ISRO), and was ranked as a high priority by park staff and biologists at a scoping workshop held by the National Park Service Great Lakes Inventory and Monitoring Network in 2000. Scientists and managers defined an assessment of the fish communities of nearshore waters to include an inventory of species, estimates of species abundances, descriptions of species distributions, and identification of habitat associations. The information generated by coupling this assessment with future monitoring of nearshore fish communities was judged to be crucial in tracking changes in fish populations and communities as the result of species reintroductions, species rehabilitations, changes in management approaches, and environmental and biological perturbations. Such a monitoring program would provide the information necessary to scientifically manage and protect nearshore fishery resources, particularly when management and research are partnered with other Department of Interior agencies, particularly U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service, and Michigan and Wisconsin Departments of Natural Resources and Lake Superior tribal agencies. Descriptions of relative population densities and community structures would also provide the parks with information useful for developing interpretative programs to educate visitors on natural resources influenced by recreational use inside the parks, commercial use inside and outside the parks, and habitat and environmental alterations outside the parks.

Following the recommendations of the 2000 workshop, our assessment of the fish communities in the nearshore zones of APIS and ISRO addressed the following objectives:

1) Conduct an inventory of nearshore fish species.
2) Describe relative fish population abundances.
3) Describe fish community structure/composition.
4) Relate fish community structure/composition to habitat characteristics of nearshore waters.
5) Relate characteristics of nearshore fish communities to offshore fish communities in APIS.

6) Compare the efficacy of different sampling gear to assess nearshore fish communities.
7) Provide guidance for establishing a long-term monitoring program for fish communities of APIS and ISRO.

For purposes of our study, we defined nearshore habitat as waters ≤ 15 m depth along shorelines of Lake Superior. This nearshore zone includes the depth where the thermocline intersects the lakebed in late summer in Lake Superior (10-15 m), and represents the area where the water column and the substrate are subject to seasonal warming and cooling (Edsall and Charlton 1997). Included in nearshore habitats are connected water bodies such as tributary mouths with connecting channels and backwaters, embayments, and wetlands. A Great Lakes coastal wetland is any naturally occurring shallow body of water containing aquatic vegetation directly connected to one of the Lakes and is influenced by seiches and changes in water levels (Keough et al. 1999). Wetland habitat may occur in marshes, bogs, marshy heads of bays, in connected backwaters and secondary channels along mouths of streams. Nearshore waters and associated coastal wetlands in the Great Lakes provide important spawning and nursery habitat for offshore, nearshore and wetland-dependent species (Chubb and Liston 1986; Stephenson 1990; Jude and Pappas 1992; Wei et al. 2004). The Nature Conservancy estimates that 80% of the fish species in the Great Lakes use nearshore areas for part of their life cycle (Chow-Fraser and Albert 1999). Using distributional data such as the "Atlas of spawning and nursery areas of Great Lakes Fishes" (Goodyear et al. 1982) and various unpublished individual inventories, Wei et al. (2004) developed a grouping of species complexes (taxocenes) for Great Lakes fishes according to major habitat associations:

1) Great Lakes taxocene: primarily associated with open water/offshore and only use tributaries to spawn and do not depend on wetland habitats.
2) Transitional (intermediate) taxocene: includes species that use both offshore and nearshore habitats and depend on wetlands for spawning or nursery habitat.
3) True wetlands taxocene: includes species that are either permanent residents of wetlands or those that migrate to wetlands for spawning, nursery, and shelter (very dependent on wetlands).

Although this classification is based primarily on presence/absence data, it provides a basis for understanding the relationships between species distributions, life history requirements, and major habitat associations. Wei et al. (2004) found that the Great Lakes fish community uses nearshore habitat, especially coastal wetland habitat, disproportionately to availability. Not surprisingly, the open water/offshore taxocene was strongly associated with rocky and bedrock shorelines and the intermediate and wetlands taxocenes were associated with low gradient wetland shorelines. However, early life history stages of some cold water offshore species such as lake herring (*Coregonus artedi*), lake whitefish (*C. clupeaformis*), and burbot (*Lota lota*) were associated with nearshore wetland habitats (Wei et al. 2004).

Coastal wetlands provide warmer, more productive habitats that are sheltered from the often harsh conditions of open water and shoreline exposed to the open lake (Keough et al. 1999; Wei et al. 2004). Coastal wetlands are important to fish because the presence of emergent and submerged vegetation provides shelter and an invertebrate food resource for small and juvenile fish (Chow-Fraser et al. 1998; Lougheed and Chow-Fraser 1998) and substrate for epiphytic algae upon which larval and juvenile fish feed (McNair and Chow-Fraser 2003). Because of the high level of usage and dependency of Great Lakes fishes on nearshore waters and associated wetlands, the contribution of these habitats to the food base of the Great Lakes is substantial and their rapid loss and degradation have important implications for the future health of Great Lakes fish communities (Chubb and Liston 1986; Chow-Fraser and Albert 1999). Unfortunately, there have been few detailed studies of food webs and community structure, life histories, and habitat associations of fishes in nearshore waters of the Great Lakes (exceptions include Chubb and Liston 1986; Jude and Pappas 1992; Keough et al. 1996; Wei et al. 2004).

In contrast to the Great Lakes, nearshore waters of inland lakes have been studied more extensively; e.g., Werner et al. (1977) studied habitat partitioning in fish communities occupying the littoral zones of two small glacial lakes in Michigan. Lyons (1989) and Magnuson and Lathrop (1992) analyzed long term data series on nearshore fish assemblages in Lake Mendota, Wisconsin and noted a decline in community structure due to a shift in dominance to a few species since the late-1980s. They linked the decline in community structure to changes in watershed-level inputs, particularly increased nutrients and sediments, which were associated with increased urbanization. Benson and Maguson (1992) studied nearshore fish communities in six Wisconsin lakes and showed that community structure was driven by variation in habitat structure and patch size. They also applied the conceptual framework of Tonn (1990) and Tonn et al. (1990) to identify continental, regional and local processes that act like filters to determine local fish community structure in nearshore waters. More recently Hatzenbeler et al. (2000) showed that seasonal changes in habitat associations of nearshore fishes in five northern Wisconsin lakes were determined largely by seasonal changes in habitat structure caused by growth of aquatic macrophytes. Drake and Pereira (2002) studied nearshore fish communities of 52 lakes in Minnesota to develop a fish-based index of biotic integrity (IBI) and found that IBI scores reflected differences in trophic state, aquatic vegetation, and land use patterns in lake watersheds.

The Lake Superior Committee and the Lake Superior Binational Program defined nearshore aquatic habitat as waters 0-80 m depth (LaMP 2000; Horns et al. 2003) and maintaining this nearshore habitat and its fish communities is a prime objective of natural resource agencies (Horns 2003; Ebener *in press*). However, nearshore waters according to our more restrictive definition (≤ 15 m depth) are not targets of past and present monitoring efforts by state, tribal, or federal agencies. Most monitoring in Lake Superior is focused on the fish populations of offshore waters (> 15 to < 100 m depth); two primary examples include annual lake-wide bottom trawl assessments conducted by the U.S. Geological Survey (Gorman and Hoff *in press*) and gill net surveys by state and tribal agencies (Hansen 1994; Ebener *in press*). Historically, these assessments have focused on determining the status of lake trout (*Salvelinus namaycush*) and preyfish populations for the purpose of restoration and management of lake trout stocks (Hansen 1994; Bronte et al. 2003; Ebener *in press*). Since 1977, the natural resource agencies in the Great Lakes region have agreed to address management and restoration of Great Lakes fishes from a fish community perspective and developed an initial set of objectives (Great Lakes Fishery Commission 1997). Recognizing the potential contribution of nearshore habitat (including the ≤ 15 m depth zone, tributaries and wetlands) to the production of Lake Superior fish stocks, the habitat objective was to “achieve no net loss” (Horns et al. 2003). Despite this primary goal, habitat requirements and associations of individual species and their communities remain largely undescribed (particularly in the 0-15 m depth zone) (Horns et al. 2003). Moreover, little is known about the trophic and energetic contribution of nearshore habitats (≤ 15 m depth) and their communities to the greater Lake Superior ecosystem.

The few studies that have been conducted on nearshore fish communities in Lake Superior have focused almost exclusively on peripheral lake habitat in the lower St. Louis River and estuary and Chequamegon Bay. Long-term monitoring and research on the fish community of the lower St. Louis River (1989-2004) was focused on the impact of exotic Eurasian ruffe (*Gymnocephalus cernuus*) on the native fish community (Ogle et al. 1996; Bronte et al. 1998). Keough et al. (1996) compared the food webs of the St. Louis estuary and the open lake using a stable isotope analysis. They found that the food webs were distinct and that a number of open lake fishes used the lower St. Louis River, estuary, and associated wetlands as spawning and rearing habitat. An analysis of a long term data set from Chequamegon Bay (1973-1996) by Hoff and Bronte (1999) identified two fish communities: a cool-warm water assemblage that was associated shallow water (< 3.0 m) and a cold water assemblage associated with deeper water (> 3.0 m). Bioenergetic models of the fish community in Chequamegon Bay showed that cool-warm water species predominated and were resident and cool-warm water predators accounted for 90% of total prey consumption (Devine 2002). Cold water species from the open lake were less abundant and seasonally transient and contributed much less overall to the food web.

METHODS

Field

Fish were sampled from nearshore waters of APIS and ISRO (Figs. 1-3) during the summers of 2003 (APIS and ISRO) and 2004 (ISRO) using a combination of gear types: bottom trawls (APIS), Windermere traps (APIS and ISRO), and fyke nets (ISRO). Fish sampling was conducted at nearshore sites where aquatic habitat had been previously characterized (*Habitat Assessment*, below).

APIS

During fall 2002, we used underwater video equipment to visually inspect shoreline habitats of prospective sample sites to classify them as low or high gradient and having sand or rock as predominant substrates. We then established eleven sample stations in a systematic-random fashion inshore from the offshore USGS deepwater assessment stations, three stations in a systematic-random fashion in estuaries and stream mouths (Sand Island and north and south Stockton Island), and nine stations in a stratified-random fashion so that the prevalent shoreline types (low and high gradient sand; low and high gradient rocky) were represented (Fig. 2). Prior to fish sampling, nearshore habitat was further characterized at each sample station as described below (*Habitat Assessment*). Further habitat characterization permitted classifying stations as low gradient (< 4.2° slope), high gradient (≥ 4.2° slope) and by primary substrates (sand, gravel, cobble, boulder, or bedrock).

The intent of pairing sampling locations in the nearshore zone (wetted edge to 15 m depth) with offshore USGS stations was to allow direct comparison of catch data from the

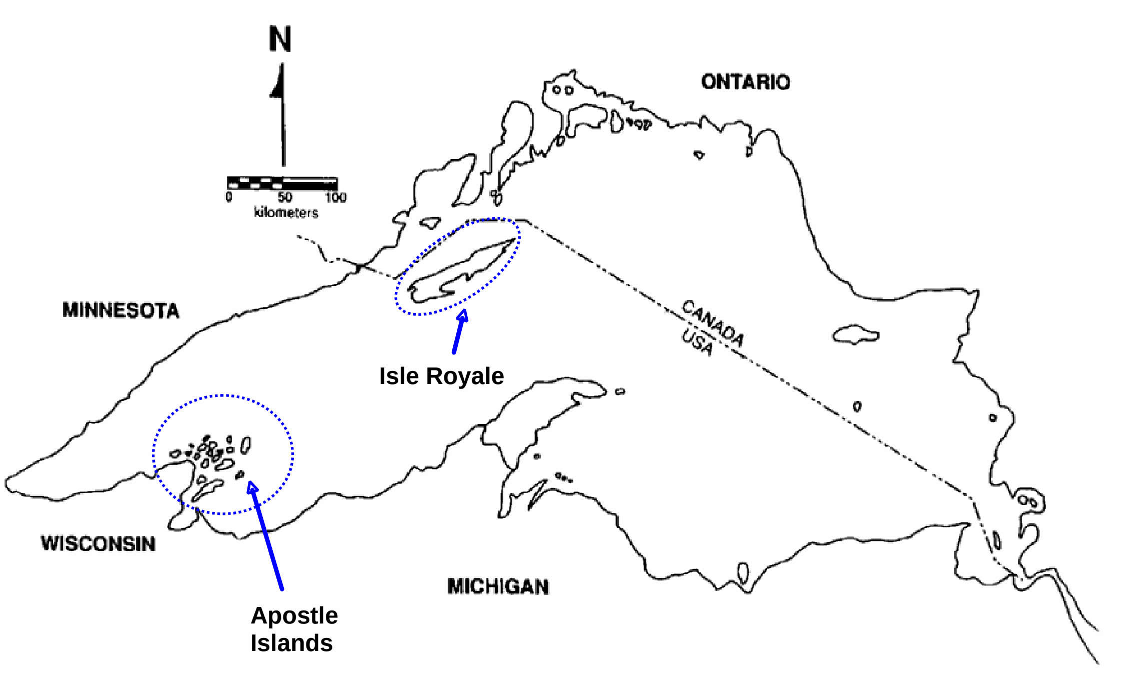


Figure 1. Location of Apostle Islands and Isle Royale in Lake Superior. These areas are under the management of the National Park Service as the Apostle Islands National Lakeshore (APIS) and the Isle Royale National Park (ISRO).

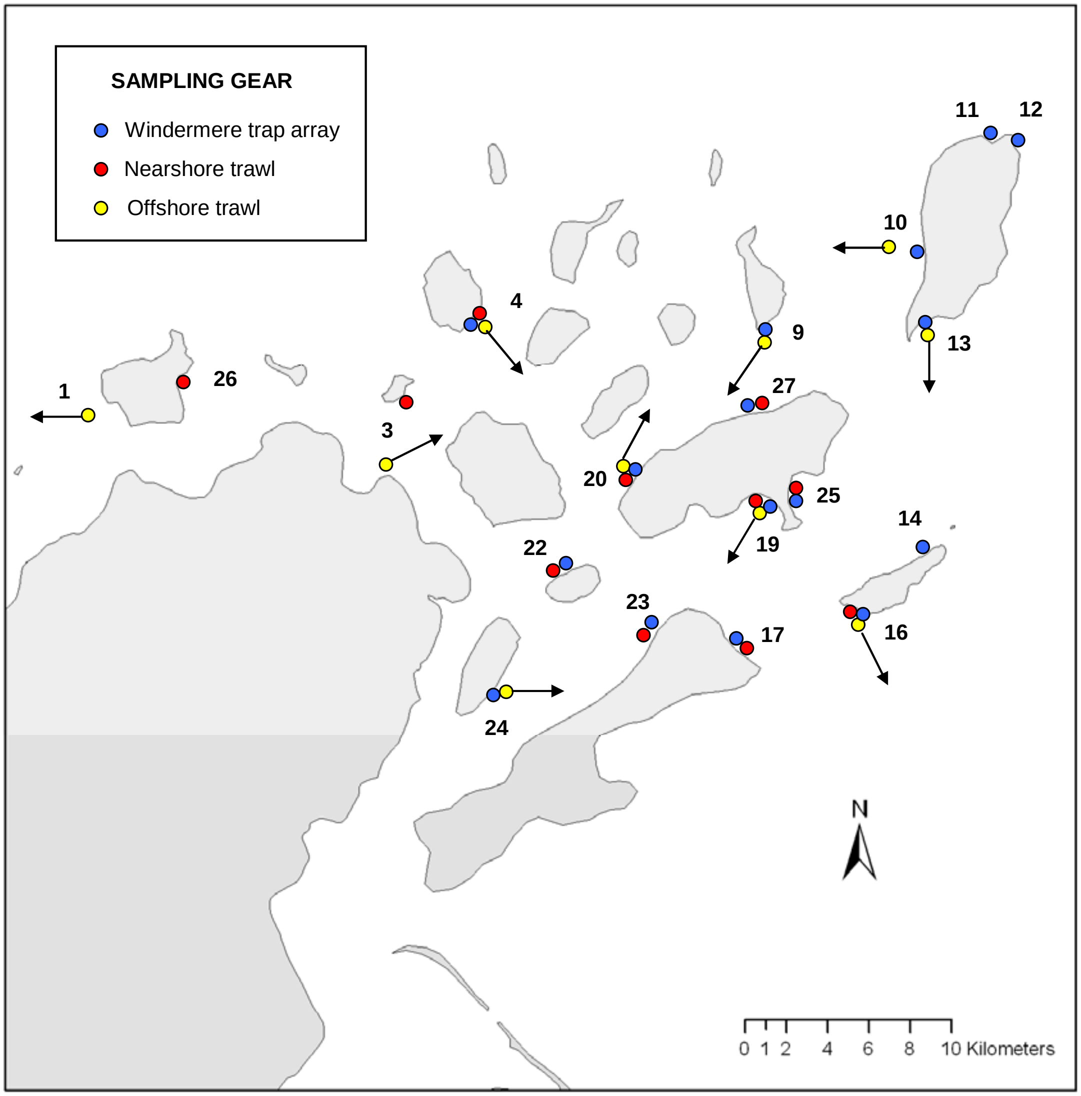


Figure 2. Fish community sampling locations in the Apostle Islands, Lake Superior, 2003-2004. Numbers refer to sampling stations described in Appendix A. Windermere traps were set in linear arrays of 12 traps in the nearshore zone (≤ 15 m depth). Nearshore trawling was conducted with a 5.2 m bottom trawl in the nearshore zone. Offshore trawling was conducted with a 12 m bottom trawl by USGS, Lake Superior Biological Station, during spring of 2003 and 2004. Offshore trawl tows started at ~15 m depth and continued to ending depth of ~80 m. Arrows indicate the direction and approximate length of the offshore trawl path (~1.6 km).

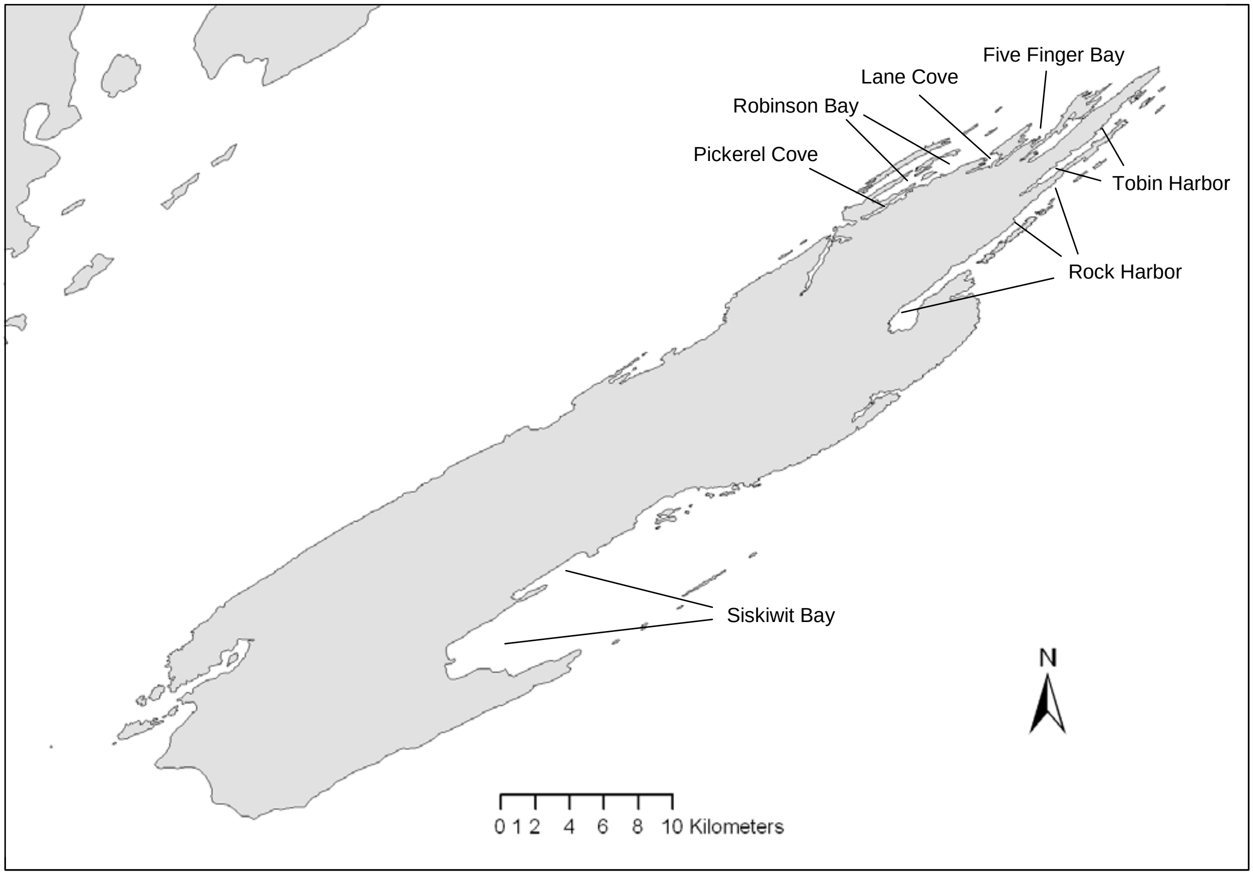


Figure 3. Fish community sampling locations in Isle Royale, Lake Superior, 2004. Embayments and approximate areas where fish communities were sampled with arrays of Windermere traps and fyke nets are shown. Detailed descriptions of the sample sites are listed in Appendix C.

nearshore zone with that of the offshore zone (> 15 m depth). The depth range of offshore samples from USGS annual spring bottom trawl assessments and special summer bottom and mid-water trawl assessments was > 15 to 120 m depth (Stockwell et al. 2005; Gorman and Hoff *in press*; Yule et al. *in press*. This application was intended specifically for APIS where the complementation of nearshore and offshore samples would allow a seamless characterization of fish communities from wetted edge to depths of 120 m, and in most cases well beyond the 0.25 mile park boundary.

Bottom trawls and Windermere traps were used to sample nearshore fish communities in APIS. We used a semi-balloon bottom trawl with 5.2 m foot rope and 6.4 mm bar mesh cod end towed from a 7 m boat as described in Ogle et al. (1995) to sample fish in areas with low gradient and fine substrates. Originally we attempted to use a 12 m trawl, but we found that nearshore areas could only be sampled with a smaller trawl in combination with a smaller vessel. At each sample station in low-gradient habitat, fish communities were sampled during daylight hours by trawling along three replicate parallel transects arranged perpendicular to shore, starting at a depth of 1 m and continuing for 10 minutes but not exceeding a depth of 15 m. Sampling effort was expressed as area swept by the trawl: width of the trawl opening under tow (4.0 m) by the rate of the tow in meters per minute (66.8 m) by duration of the tow in minutes.

At the beginning of the field work in summer 2003, we found that trawling was only successful in areas of low slope and sandy substrates, which left us without samples from areas with high slopes or with rocky substrates. To remedy this problem, in 2003 we deployed modified Windermere traps (Edwards et al. 1998) in APIS at sites where trawling was not possible, i.e., steep bedrock areas and in low-slope areas strewn with boulders and cobbles. Windermere traps are passive fish capture devices similar in construction to large minnow traps, with conical entrances on both ends and a flat bottom to resist rolling. The Windermere traps used were approximately 1.25 m long by 0.8 m diameter and covered with 6.4 mm mesh nylon netting. We deployed 12 traps in an array along a transect perpendicular to shore beginning at ~1 m depth (minimum effective sampling depth of the trap) and then spaced at ≥ 5 m horizontal intervals between traps out to a maximum depth of 15 m, thus covering the same range of depths as would be sampled by a bottom trawl. After setting, traps were soaked (fished) for 24 hours before lifting. The placement of these arrays coincided with sampling grids where habitat was previously measured (*Habitat Assessment*, below). Our methodology of setting traps in arrays for fixed 24 hr soak times was an attempt to reduce capture and escapement bias of trap catches and to minimize the area from which fish are recruited to the traps (Hamley and Howley 1985; Gorman 1994). Because we did not sample trawable sites with Windermere traps in 2003, during the 2004 field season we resampled 9 of 12 locations in APIS with both bottom trawls and Windermere traps and also resampled two of six untrawlable steep/rocky sites with Windermere traps. The intent of this resampling was to apply a common sampling method across most of the trawlable sample sites and compare the results of the two methods. We recorded the following data, as appropriate, for each trap set or trawl haul: habitat type (gradient (low: < 4.2° slope, high: ≥ 4.2° slope) and primary substrates (sand, gravel, cobble, boulder, or bedrock), depth, GPS location, time, and duration. For each trap set or trawl haul, up to 50 individuals of each species captured were randomly selected and measured for total length (TL) and weighed to the nearest 0.1 gram. When more than 50 individuals per species were captured, the additional fish were counted and mass weighed. Vouchers of each species from each station were preserved in 10% formalin.

ISRO

In ISRO we had to rely on Windermere traps and fyke nets to obtain comparative data on nearshore fish communities (Figs. 1, 3). Trawls were not used because of the lack of trawlable habitat in the nearshore waters of ISRO. Results of a previous assessment of ISRO nearshore habitat in 2001-2003 (Gorman et al., *in press*; see *Habitat Assessment* below) were used to guide the establishment of a representative set of study sites to characterize nearshore fish communities in 2004. During summer of 2004, fish were sampled in the nearshore zones of seven embayments: Siskiwit Bay, Rock Harbor, Tobin Harbor, Five Finger Bay, Lane Cove, Robinson Bay, and Pickerel Cove (Fig. 3). We were not able to sample Washington Harbor, Todd Harbor or McCargoe Cove because of a lack of logistical support. Windermere traps were set in arrays along transects in the same manner as at APIS. In each embayment, trap arrays were distributed in a stratified-random fashion with two arrays in protected habitat (> ½ distance from mouth to head of bay) and two arrays in unprotected habitat (≤ ½ distance between mouth to head of bay).

When possible, we located trap arrays in different nearshore habitat types within protected and unprotected portions of an embayment, e.g., low gradient-fine substrate, low gradient-coarse substrate, high gradient-rocky, and bedrock. In addition to Windermere traps, we set 10 fyke nets (0.92 x 1.54 m opening, 15.5 m long lead, 6.4 mm mesh) individually in each embayment distributed in a stratified-random fashion with 5 sets in protected and 5 sets in unprotected habitat and distributed among the prevalent nearshore habitat types as with Windermere traps. Each fyke net was set with the lead tied to shore and stretched perpendicularly out to a distance of ~15 m, depending on bottom slope. Set in this manner, each fyke net sampled fish from a zone between 0 and ~15 m from shore. Both Windermere and fyke nets were set at each location for 24 hours. For each Windermere trap or fyke net set we recorded habitat type, depth, GPS location, time of set, and duration of set. Fish catches were enumerated in the same manner as for APIS.

Habitat Assessment

Nearshore habitat in APIS and ISRO is described in Gorman et al. *(in press*). We adapted stream habitat assessment methods of Gorman and Karr (1978) and Gorman and Stone (1999) to nearshore waters of lakes in a manner similar to Hatzenbeler et al. (2000). To summarize, we used a point-based sampling method whereby habitat data were collected at intersections of 2 x 2 m cells within a grid 20 m long and 4 m wide oriented perpendicular to shore. In APIS, a single habitat grid was sampled in association with each fish sampling station. In ISRO, sample grids were spaced at 1000 m intervals around the perimeter of bays to allow detection of a gradient in habitat characteristics from protected areas at the head of an embayment to sites at the mouth that were exposed to the open lake. Fish sampling was conducted at locations of habitat sampling grids. At each sample point, depth, substrate, and cover variables were recorded (*sensu* Gorman and Stone 1999). Depth was measured to the nearest cm. Substrate type at each sample point was categorized according to a modified Wentworth (1922) scale (*sensu* Gorman and Karr 1978; Platts et al. 1983; Hatzenbeler et al. 2000): 0-silt, 1-fine sand or silty-sand, 2-coarse sand, 3-small gravel, 4-large gravel/pebble, 5-small cobble, 6-large cobble, 7-small boulder, 8-large boulder, 9-bedrock. At each point, substrate contacting or overlapping a 5-cm radius was inspected; the dominant substrate type had the greatest areal coverage within the 5-cm radius, and subdominant substrate types were listed in order of decreasing areal coverage (*sensu* Gorman and Stone 1999). We used mean substrate size to characterize entire grids; fine substrate was defined as consisting of silt or sand or mixed silt and sand, intermediate as consisting of gravel or mixed sand-gravel-small cobble, and coarse as consisting of rock, boulder, or bedrock substrate. Slope was expressed as the average change of depth from wetted edge to the outermost three points in the grid. Gradient was defined as low (average slope of $< 4.2°$) and high (average slope $\geq 4.2°$). In ISRO, the relative degree of protection of each grid in an embayment from the influence of the open lake was expressed as the ratio of distance in km from a grid location to the mouth of the bay divided by the width at the mouth of the bay (EEI, embayment exposure index). Values < 4 (low protection) were typical of areas exposed to the open lake near the mouth of embayments, values of 4-7 (intermediate protection) were associated with areas near the midpoints of embayments, and values > 7 (highly protected) represented areas found at the head of long narrow embayments.

Analysis

Our analyses addressed the first six objectives of this study. The final objective, *Provide guidance for establishing a long-term monitoring program for fish communities of APIS and ISRO,* will be addressed in the Discussion.

Inventory of fish species

Composition of nearshore fish communities was estimated by tabulating species counts by sample location, sampling method, and habitat type. Since nearshore waters provide nursery habitats for many offshore species, we partitioned catch data by adult and juvenile life stages. Our use of 6.4 mm mesh netting in all of our sampling devices allowed us to capture fish as small as 30 mm TL (Stone and Gorman 2006) and thus we could sample both juvenile and adult life stages of fishes inhabiting nearshore waters. We considered an individual to be an adult if it was > 70% of adult size as determined from literature sources (Scott and Crossman 1973; Becker 1983).

Fish abundance

The intent of our sampling design was to use active and passive sampling gears to sample the same locations of nearshore habitat with similar areal coverage. This allowed comparison of catch composition between passive and active sampling gears and comparison of catch rates by gear across the range of habitats sampled. However, because Windermere traps and fyke nets are passive sampling devices and sample indeterminable areas and bottom trawls are active sampling devices and sample measurable areas, we could not combine catch rate data among these gear types. We expressed CPE (catch-per-effort) abundance from bottom trawl catches as number/ha and CPE from fyke nets and arrays of Windermere traps and as catch/day (soak times were standardized at ~24 hrs). For 5.2 m bottom trawls, total catch was divided by the estimated area swept during a tow. As an example, a 10 minute tow at ~4 km/hr covering 667 m with a trawl spread ~3.8 m, sweeps an area of ~0.25 ha. For other USGS bottom and mid-water trawl data, CPE abundance was expressed as number/ha using established formulas based on gear mensuration data (Gorman and Hoff *in press*; Yule et al *in press*). Catch rates for fyke nets were expressed as catch per individual fyke net per day. Catch rates for Windermere traps were expressed as catch per array per day because Windermere traps were set in linear arrays of 12 traps along transects perpendicular to shore. Also, catch composition of traps and nets reflected the full range of diel activity because they were set for 24 hr, whereas bottom trawl catches represented only daytime species composition.

Community structure

Structure of nearshore fish communities was analyzed first by tabulating abundance data by gear type or combination of gears and graphically comparing community composition among prevalent nearshore habitat types for each park unit. We then used Percent Similarity (PS; Schoener's 1970) and the reciprocal of PS, Percent Change (PC; Gorman1988) to assess the amount of difference in community structure by habitat, location, and gear type:

$$PS = [1-\sum |p_{ij}-p_{ik}| /2]100$$

$$PC = [\sum |p_{ij}-p_{ik}| /2]100$$

Where p_{ij} represents the proportion of the ith species in sample j and p_{ik} represents the proportion of the ith species in sample k. Values of PS range from 0% (completely dissimilar) to 100% (identical composition). Values of PC range from 0% (identical composition) to 100% (completely dissimilar).

We note that PC is essentially the same index as Gauch's (1982) Percent Dissimilarity and Benson and Magnuson's (1992) measure of Community Heterogeneity (CH):

$$PD = [1 - 2\sum(MIN(p_{ij},p_{ik}))/ \sum(p_{ij}+p_{ik})]100$$

Values of PD range from 0% (identical composition) to 100% (completely dissimilar).

We used the Shannon index (Shannon and Weaver 1949) to assess species diversity of fish communities among habitat types, sampling methods, and park units, and was expressed as

$$H' = - \sum p_i \log p_i$$

where p_i represents the proportion of the ith species in the community sample and "log" refers to the natural logarithm. Increasing values of H´ correspond to increased species richness (number of species in sample) and increased equivalency of species abundances. The anti-log of H´ (EXP H´) represents the number of equivalent species in the sample. If all species are equivalent, the anti-log of H´ will be the number of species in the sample (Pielou 1974).

To summarize comparisons of nearshore community structure in relation to habitat, we used combined catch composition data (raw abundance data) from various sampling gear by location or habitat type. Because various fishing gear were used to sample the same community in the same habitats or locations, a combined sample was more representative of the resident nearshore fish community and could be used to reveal further information on community composition and structure. As suggested by Jackson and Harvey (1997) catches from different sampling gears should not be simply added because of different inherent gear biases and variability in estimating fish abundances. Rather, investigators should consider restricting data to presence/absence format or to adjust the catch data to address differences in methods of capture. However, Drake and Pereira (2002) argued convincingly that they could add the catches from fyke nets and electrofishing taken in nearshore waters of inland lakes in Minnesota because they sampled within the same area along shorelines. Likewise, Hatzenbeler et al. (2000) combined (added) electrofishing and seine capture data from nearshore zones of inland lakes in Wisconsin. In our case, we also used two gear types to sample within the same areas or habitats in nearshore waters, so we had a basis for combining catch data to evaluate composite species composition.

When combining catch data from different sample gears, as done by Drake and Pereira (2002), one should consider whether abundances should be added or averaged. If the proportion of a species is equal in both samples, then the relative gear bias is the same and the abundances should be averaged. However, if the proportions are very different, then gear bias is high for that species and the abundances should be added. We adjusted raw abundance data for samples from two gear types to accommodate a gradient of bias for individual species as follows:

The Adjusted Species Abundance (ASA_i) in the combined sample was expressed as:

$$ASA_i = (P_{ij} + P_{ik})/2 \times SA$$

Where P refers to the proportion of i^{th} species in samples j and k, and

$$SA \text{ (sample adjustment)} = 1 + |P_{ij} - P_{ik}|/(P_{ij} + P_{ik})$$

Thus, when species fractions are the same in both samples, SA =1.0 and the combined data is the mean of both samples. When species fractions are fully different, SA=2 and the combined data is the addition of both samples. The new proportion for the i^{th} species in the combined catch is expressed as Adjusted Species Proportion (ASP):

$$ASP_i = ASP_i / \sum_{i = 1-n} ASP_i$$

Comparisons of nearshore and offshore fish communities at APIS

Bottom trawl assessments conducted in the Apostle Islands each spring by USGS (Stockwell et al. 2005) provided reference data on the composition of offshore fish communities to compare with our samples of nearshore communities. Offshore fish communities were sampled during daytime at ten sites in the Apostle Islands with a large 12 m bottom trawl towed cross-contour (perpendicular to shore) from a starting depth of ~15 m and continuing for a distance of ≥ 1.5 km. Catches from these trawl tows provide integrated samples of the fish community over a depth range of ~15 m to ~80 m. To facilitate comparison, we paired ten of our nearshore sampling stations with the ten offshore trawling stations sampled by USGS (Fig. 2; Append. A). Results of USGS spring bottom trawl samples taken during 2003-2004 were summarized and compared with fish community composition from all 27 nearshore sites.

During the summer of 2004, Yule et al. (*in press*) conducted a series of on-contour (parallel to shore) trawl samples in offshore waters of the Apostle Islands. Trawl tows were taken at target depths of 30, 60 and 120 m with bottom and mid-water trawls during both day and night, which provided a comprehensive dataset of the entire offshore fish community. To gauge how the fish community changed along a depth gradient from nearshore waters to the offshore zone, we compared community composition from our nearshore samples (≤ 15 m depth) with those taken by Yule et al. at 30, 60, and 120 m.

Comparison of different sampling gear to assess nearshore fish communities

We evaluated the efficacy of active (trawls) and passive sampling gear (traps, fyke nets) to assess community structure in APIS and ISRO by comparing species composition, measures of PC in community composition, and H´ measures of diversity. For APIS we compared catch composition data from Windermere trap arrays and bottom trawls from sites where both gear types were used (low gradient, fine substrate habitats). For ISRO we compared catch composition data from Windermere traps and fyke nets conditioned by habitat type and embayment protection (EEI). Because Windermere and fyke nets were deployed over the same range of habitats and EEI in ISRO, data from the two sampling gears were highly complementary. However, comparisons of community structure between ISRO and APIS were limited to Windermere trap catch data as this was the only common sampling gear used in both areas and across the full range of nearshore habitat types.

RESULTS

Apostle Islands National Lakeshore

Species inventory

During the summers of 2003-2004 we completed 69 tows with a 5.2 m bottom trawl at 10 nearshore sample locations, which were complemented by arrays of Windermere traps set at 16 nearshore locations of which 9 sites were in common with trawl samples; (Fig. 2; Append. A). Bottom trawls and Windermere trap arrays both yielded 15 species, though not the same composition, and in combination yielded 21 species. Rainbow smelt, burbot, brook stickleback, ninespine stickleback, lake chub, johnny darter, log perch and slimy sculpin were the most common species (Append. B). Ten offshore bottom trawl sampling locations complemented nearshore sites and yielded 21 species, though not of the same composition as the nearshore samples. A total of 29 fish species were captured in APIS during 2003-2004 in near and offshore waters (Table 1).

Trawls were used predominantly in low-slope, sandy nearshore areas with aquatic vegetation (e.g., eastern shore Sand Island), and without vegetation (e.g., Presque Isle Bay). Catches from bottom trawls were strongly dominated by ninespine stickleback. As a result, H´ species diversity measures were relatively low for trawl catches compared to trap catches (Table 2). Other common species in trawl catches included rainbow smelt, trout-perch, johnny darter, log perch, and slimy sculpin (Fig. 4). Species unique to trawl catches included rainbow smelt, round whitefish, lake whitefish, lake herring, longnose dace, and ruffe (Table 1; Append. B).

Windermere traps were used successfully in all nearshore habitat types and, unlike trawl catches, as many as five species were co-dominant in trap catches: slimy sculpin, burbot, lake chub, ninespine stickleback, and brook stickleback (Fig. 5). As a result, H´ species diversity measures for trap catches were higher than those for trawls (Table 2). Species unique to trap catches included rock bass, longnose sucker, brook stickleback, lake chub, blacknose dace, and mottled sculpin (Table 1; Append. B). In areas where traps were used, fish were generally more abundant at depths > 4 m and were most abundant in steep bedrock habitat found on the east side of Basswood Island (Station 24; Append. B).

Table 1. Species captured in the APIS during 2003-2004. Colors are used to identify species in figures. Records for USGS trawls are from USGS, Lake Superior Biological Station, Ashland, Wisconsin and Yule et al. (*submitted*). Great Lakes fish taxocenes: 1 = coastal, 2 = intermediate, 3 = open-water (Wei et al. 2004). Thermal groups: 1 = cold, 2 = cold-cool, 3 = cool, 4 = cool-warm, (Coker et al. 2001; Wei et al. 2004).

Common Name	Scientific name	Abbr	Color	Windermere trap	5.2 m bottom trawl	12 m bottom and 17 m midwater trawls	Taxocene	Thermal Group
1 Alewife	*Alosa pseudoharengus*	ALW				X	2	1
2 Rainbow smelt	*Osmerus mordax*	RNS			X	X	2	1
3 Burbot	*Lota lota*	BRB		X	X	X	3	2
4 Brook stickleback	*Culaea inconstans*	BKS		X			1	3
5 Threespine stickleback	*Gasterosteus aculeatus*	TSS		X	X	X	3	1
6 Ninespine stickleback	*Pungitius pungitius*	NSS		X	X	X	3	1
7 Trout-perch	*Percopsis omiscomaycus*	TRP		X	X	X	2	1
8 Lake herring	*Coregonus artedi*	LKH			X	X	3	1
9 Lake Whitefish	*Coregonus clupeaformis*	LWF			X	X	3	1
10 Bloater	*Coregonus hoyi*	BLT				X	3	1
11 Kiyi	*Coregonus kiyi*	KYI				X	3	1
12 Shortjaw cisco	*Coregonus zenithicus*	SJC				X	3	1
13 Pygmy whitefish	*Prosopium coulteri*	PWF				X	3	1
14 Round whitefish	*Prosopium cylindraceum*	RWF			X	X	3	1
15 Lean lake trout	*Salvelinus namaycush namaycush*	LLT				X	3	1
16 Siscowet lake trout	*Salvelinus namaycush siscowet*	SLT				X	3	1
17 Longnose sucker	*Catostomus catostomus*	LNS		X		X	3	1
18 White sucker	*Catostomus commersoni*	WHS		X	X		2	3
19 Longnose dace	*Rhinichthys cataractae*	LND			X		2	3
20 Lake chub	*Couesius plumbeus*	LKC		X			3	1
21 Blacknose dace	*Rhinichthys atratulus*	BND		X			1	3
22 Rockbass	*Ambloplites rupestris*	RKB		X			1	3
23 Johnny darter	*Etheostoma nigrum*	JND		X	X	X	2	3
24 Logperch	*Percina caprodes*	LGP		X	X		1	4
25 Ruffe	*Gymnocephalus cernuus*	RFF			X	X	2	3
26 Mottled sculpin	*Cottus bairdi*	MTS		X			3	1
27 Slimy sculpin	*Cottus cognatus*	SLS		X	X	X	3	1
28 Spoonhead sculpin	*Cottus ricei*	SPS		X	X	X	3	1
29 Deepwater sculpin	*Myoxocephalus thompsoni*	DWS				X	3	1
				15 spp	15 spp	21 spp		

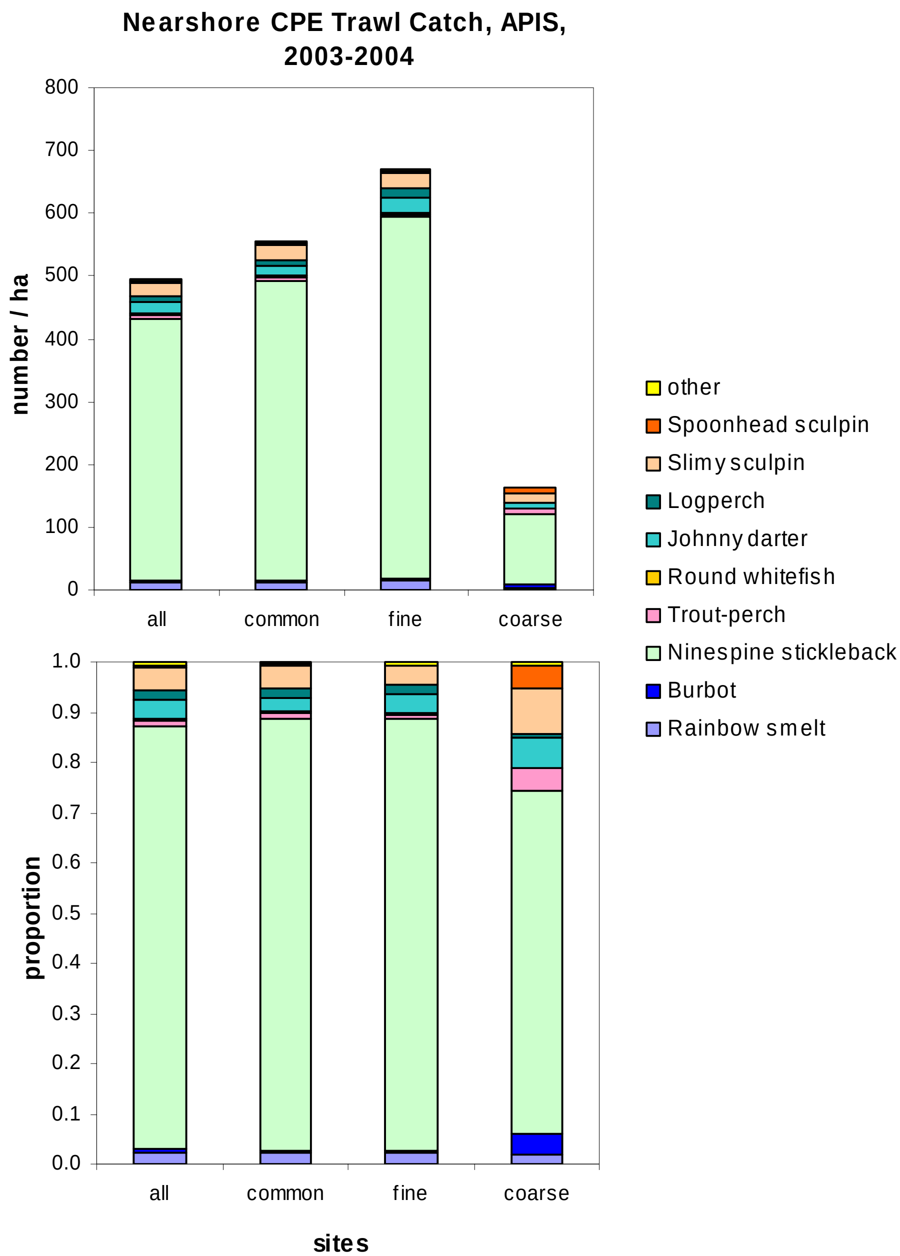


Figure 4. Density and composition of fish communities in the nearshore zone of the Apostle Islands as estimated by 5.2 m bottom trawl samples and stratified by habitat type, 2003-2004. "All" represents composition from pooling all trawl catches. "Common" represents the composition of trawl catches from sites where both Windermere trapping and trawling were conducted in 2003 and 2004. Fine and coarse represent habitats by average substrate composition: fine is dominated by sand and small gravel and coarse is dominated by large gravel, cobble, and rock. No comparisons between high and low slope sites were possible as all trawl samples were taken in low slope habitat (< 4.2°).

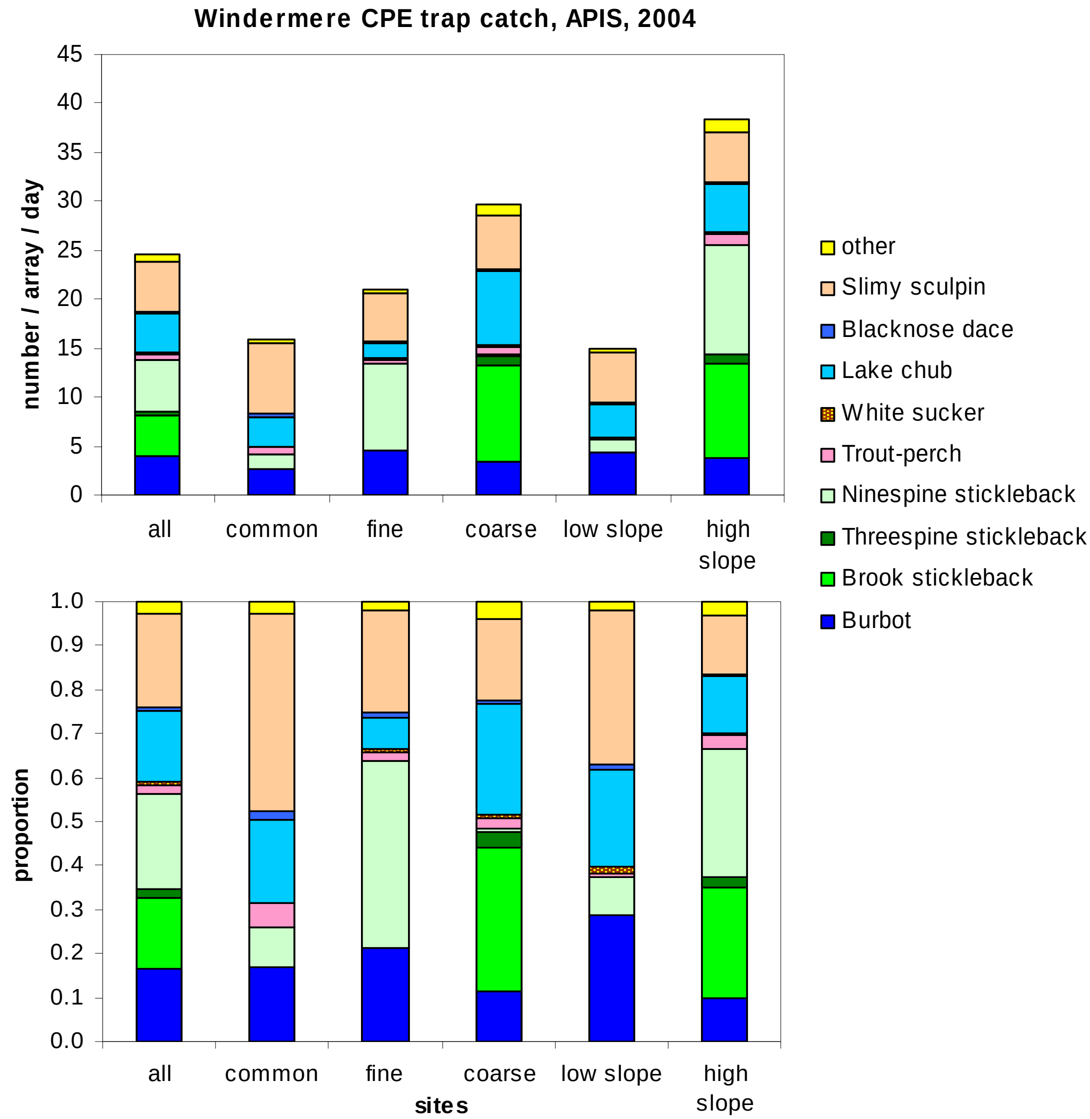


Figure 5. Catch rates and composition of fish communities in the nearshore zone of the Apostle Islands as estimated by Windermere trap samples and stratified by habitat type, 2003-2004. "All" represents composition from pooling all Windermere trap catches. "Common" represents the composition of Windermere trap catches from sites where both trawling and trapping were conducted. Fine and coarse represent habitats by average substrate composition: fine is dominated by sand and small gravel and coarse is dominated by large gravel, cobble and rock. Mean slopes > 4.2° were classified as "high" and those < 4.2° were classified as "low".

Table 2. Species richness (number of species) and species diversity (H´) measures for APIS Windermere trap and 5.2 m bottom trawl samples, 2003-2004. Species diversity is expressed as the Shannon index (H´; Shannon and Weaver 1949). The antilog of H´ (exp H´) represents the number of equivalent or co-dominant species. Number of samples refers to the sum of sites sampled or sites sampled on different dates; some sites were sampled in both 2003 and 2004 as part of a trawl-Windermere trap comparison. For trawl samples, triplicate tows were performed at each site on a given date and catches were averaged and counted as one sample. Windermere traps were set in arrays of 12 traps at each site and date and each array was counted as one sample.

Windermere traps	number					
	samples	sites	species	individuals	H'	EXP(H')
All	17	16	15	418	1.868	6.475
Common - 2004	9	9	9	143	1.564	4.776
Fine	10	10	9	210	1.475	4.370
Coarse	7	6	13	208	1.750	5.753
Low slope	10	10	9	149	1.513	4.542
High slope	7	6	14	269	1.816	6.150

5.2 m trawls	number					
	samples	sites	species	individuals	H'	EXP(H')
All	23	11	15	1359	0.746	2.109
Common-2004	9	9	3	30	0.882	2.416
Common-2003	11	9	12	1295	0.638	1.893
All Common	20	9	12	1325	0.649	1.913
Fine	13	7	14	1206	0.658	1.930
Coarse	10	4	9	153	1.199	3.316

Comparison of sampling methods

Results of side-by-side trapping and trawling from nine sites in habitats conducive to both sampling techniques in 2004 showed that trapping captured nine species, whereas three species were captured by triple-replicate trawling in the same area (Table 2; Figs. 4-5). Moreover, only 30 fish were captured in trawls in the common sites in 2004. When the comparison included trawl samples from the common sites for 2003, the number of species captured in trawls increased to 12 and the number of fish captured increased to 1295 (Table 2). However, H´ species diversity remained low for trawl samples (< 0.9) compared to the catch from common trap sites (1.564) because trawl catches were dominated by a single species, ninespine stickleback. A comparison of EXP(H´) values showed that traps yielded samples that had two to three times the number of co-dominant species as did trawl samples (Table 3).

A comparison of the composition of 5.2 m bottom trawl and Windermere trap caches from all common sites using the PC measure showed an 83% difference (Table 3). This indicated that traps and trawls sampled different components of the nearshore fish community and that the two data sets were potentially complimentary. To facilitate a comparison of fish communities in nearshore and offshore waters, we combined 5.2 m bottom trawl and Windermere trap catch data sets to provide a more complete sample of the nearshore fish community in APIS (see *Comparison of nearshore and offshore communities at APIS*, below).

Fish community structure and habitat associations

Partitioning trawl and Windermere trap catch data by nearshore habitat characteristics (slope and substrate) revealed differences in fish community structure (Tables 2, 3; Figs. 4, 5). Comparison of trawl catches from areas of fine (silt to fine gravel) and coarse (large gravel/pebble to boulder) substrates showed community composition to be 80% similar and while more species were captured over fine substrates (14 vs. 9), species diversity was considerably higher in samples taken over coarse substrates (1.199 vs. 0.658; Tables 2, 3). As will become a common theme in our results, the reason for this difference in diversity was the predominance of ninespine stickleback in areas with low slope and fine substrates. In areas with coarse substrates, there was increased abundance of brook stickleback, trout-perch, johnny darter, slimy sculpin, spoonhead sculpin, and burbot (Figs. 4-5).

Composition of Windermere trap catches varied more with substrate and slope than did trawl catches (Tables 2, 3; Fig. 5). Areas of high slope and coarse substrates harbored more species and had higher H´ diversity than areas of low slope and fine substrates (14 and 13 vs. 9 species, and 1.816 and 1.75 vs. 1.513 and 1.475, respectively; Table 3). The composition of those communities was also very different, with similarities of less than 50% (Table 3), which indicated that communities in these different nearshore habitats were relatively distinct. Communities in low slope habitats were dominated by slimy sculpin, burbot, and lake chub; in high slope habitats by nine-spine stickleback, brook stickleback, lake chub, and slimy sculpin; in fine substrates by ninespine stickleback, slimy sculpin and burbot; and in coarse substrates by lake chub, brook stickleback, slimy sculpin, and burbot (Fig. 5).

Table 3. Similarity (Schoener 1970) measures for APIS Windermere trap and 5.2 m bottom trawl samples, 2003-2004. Part A: catch composition of common sites (side-by-side sampling) and all sites are compared. Parts B, C: catch composition for different habitat types are compared. Note that there are no high and low slope comparisons for trawls as all trawl samples were conducted in low-slope habitat. Red font highlights lowest similarity values in respective sections.

A. Percent Similarity for Windermere trap and 5.2 m bottom trawl catch composition

all common sites	2004 common sites	all sites sampled
0.17	0.54	0.36

B. 5.2 m bottom trawls

	fine	coarse	all
Fine	1.00		
Coarse	0.80	1.00	
All	0.98	0.82	1.00

C. Windermere traps

	fine	coarse	low slope	high slope	all
fine	1.00				
coarse	0.43	1.00			
low slope	0.64	0.58	1.00		
high slope	0.70	0.63	0.48	1.00	
all	0.76	0.67	0.70	0.79	1.00

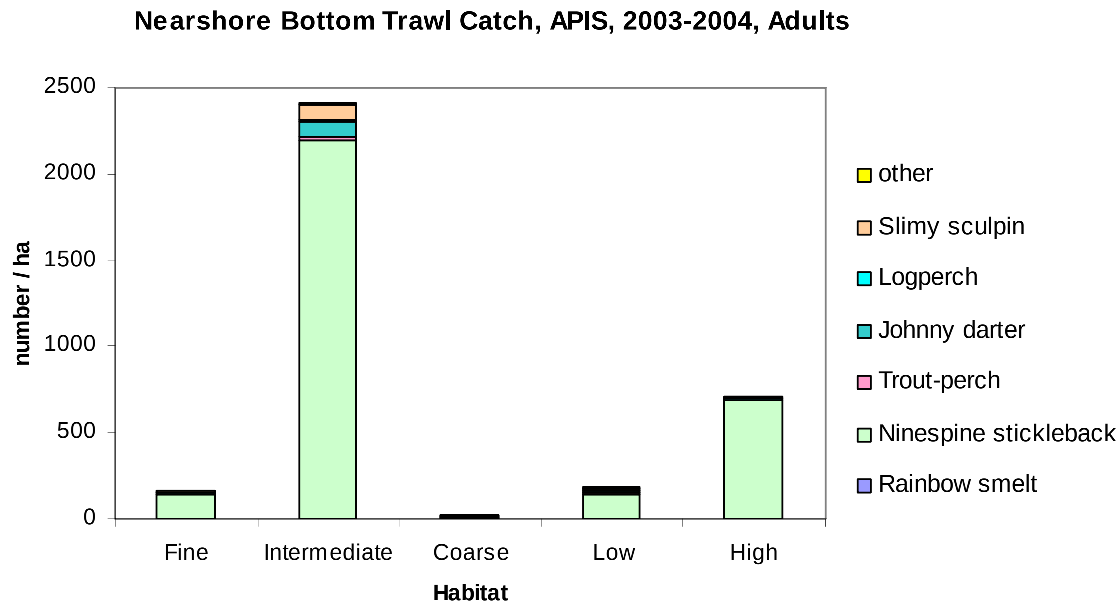
Fish-habitat associations and life stage

Most of the fish captured in 5.2 m trawls and Windermere traps were adults (66.2 and 79.4%, respectively). Results from trawl catch data showed that the highest densities of adults and juveniles were captured in areas of intermediate substrates (large gravel and small cobble in a matrix with sand and fine gravel) and as seen previously, trawl catches in this habitat type were dominated by ninespine stickleback, a nearshore species (Fig. 6). Low numbers of fish taken in areas with coarse substrates (cobble-boulder) with bottom trawls reflect the inefficiency of capturing fish with this sampling gear over rough substrates. Comparison of life stage composition between high and low slope habitats showed that adults were more abundant in areas of high slope whereas juveniles were more abundant in areas of low slope (Fig. 6). Composition of adults was more strongly dominated by ninespine stickleback (89.6%) compared to composition of juveniles (≥ 73.6%). As a result, more species were represented in the juvenile fraction of the community as reflected in trawl samples, particularly rainbow smelt, an offshore species, and log perch and trout-perch, both nearshore species (Fig. 6).

Results of partitioning Windermere trap catch data into adult and juvenile subsets yielded strong differences in habitat association by life stage. Unlike trawl catches, ninespine stickleback did not dominate catches of adults or juveniles in Windermere traps, but all sticklebacks (ninespine and brook) captured were adults (Fig. 7). We do not suspect that retention of juvenile sticklebacks in Windermere traps explained this difference because both Windermere traps and 5.2 m bottom trawls used 6.4 mm mesh. The highest catch rates for adults and juveniles were observed over coarse and intermediate substrates (Fig. 7). Sticklebacks dominated the adult fraction over coarse substrates and slimy sculpin, lake chub, and burbot dominated over intermediate substrates. For juveniles, the highest catch rates were observed over intermediate substrates and were composed of burbot, slimy sculpin, and lake chub (Fig. 7). The highest catch rates for both adults and juveniles were from areas of high slope. As observed in areas with coarse substrates, sticklebacks dominated the catches from areas of high slope. Although catch rates varied, composition of juveniles was similar in both low and high slope and in areas with intermediate and coarse substrates.

Summary of nearshore fish community composition

Comparison of catch composition from Windermere traps and 5.2 m bottom trawls showed low similarities (Table 3), suggesting these two gears sampled different components of the nearshore fish community or had very different catch biases. We combined catch data from the two gears using *Adjusted Species Abundance* to provide a summary of nearshore fish community composition and habitat associations (Fig. 8). Overall, ninespine stickleback was the dominant nearshore species but only in habitats with fine substrates and low slopes. Brook stickleback and lake chub were the dominant species in areas of coarse substrates, which also had the highest diversity (Table 2). Other predominant species included slimy sculpin and burbot, which showed similar abundances across all habitats.



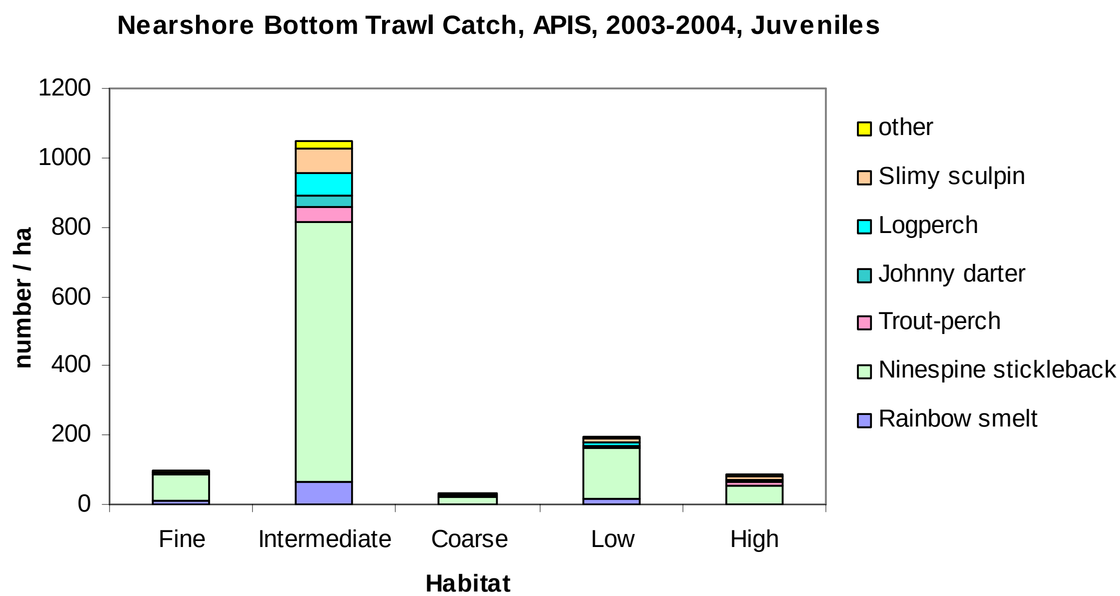
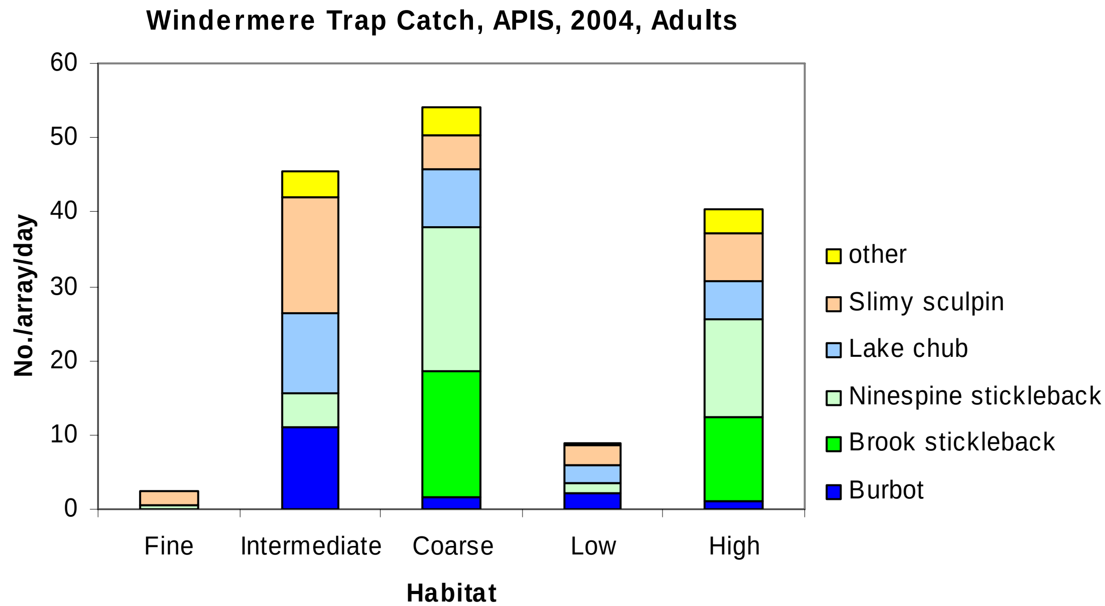


Figure 6. Density and composition of adult and juvenile fish in the nearshore zone of the Apostle Islands as estimated by bottom trawl samples and stratified by habitat type, 2003-2004. Range of mean substrate sizes (modified Wentworth scale) were fine, 0-3.0 (silt to small gravel); intermediate, > 3.0-5.0 (large gravel to small cobble); and coarse, > 5.0 (large cobble to bedrock). Mean slopes > 4.2° were classified as "high" and those < 4.2° were classified as "low".



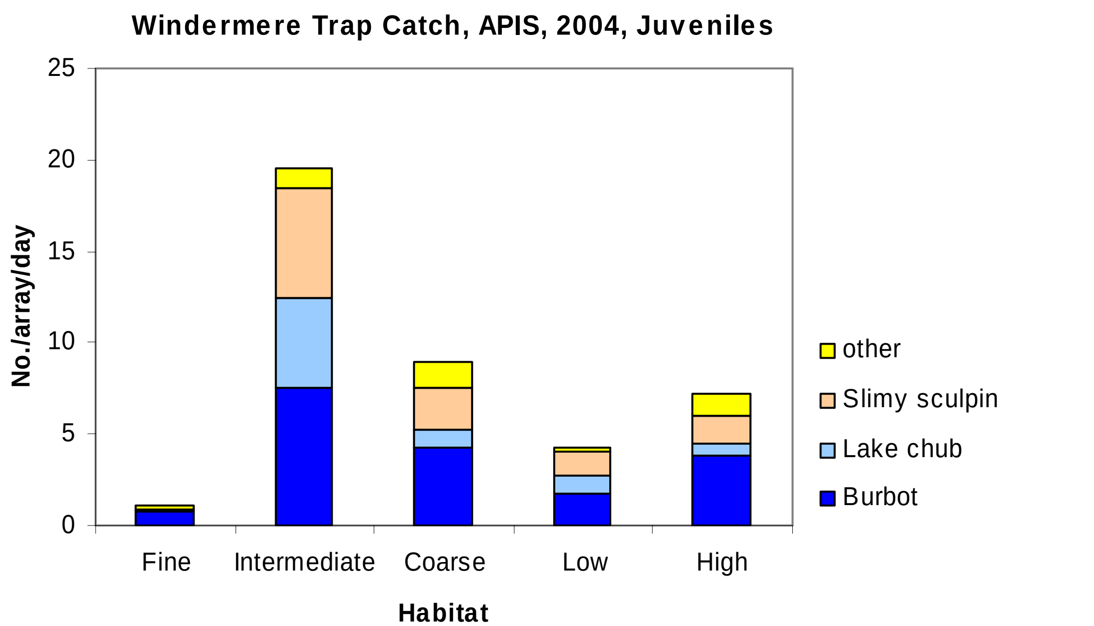


Figure 7. Catch rates and composition of adult and juvenile fish in the nearshore zone of the Apostle Islands as estimated by Windermere trap samples and stratified by habitat type, 2003-2004. Range of mean substrate sizes (modified Wentworth scale) were fine, 0-3.0 (silt to small gravel); intermediate, > 3.0-5.0 (large gravel to small cobble); and coarse, > 5.0 (large cobble to bedrock). Mean slopes > 4.2° were classified as "high" and those < 4.2° were classified as "low".

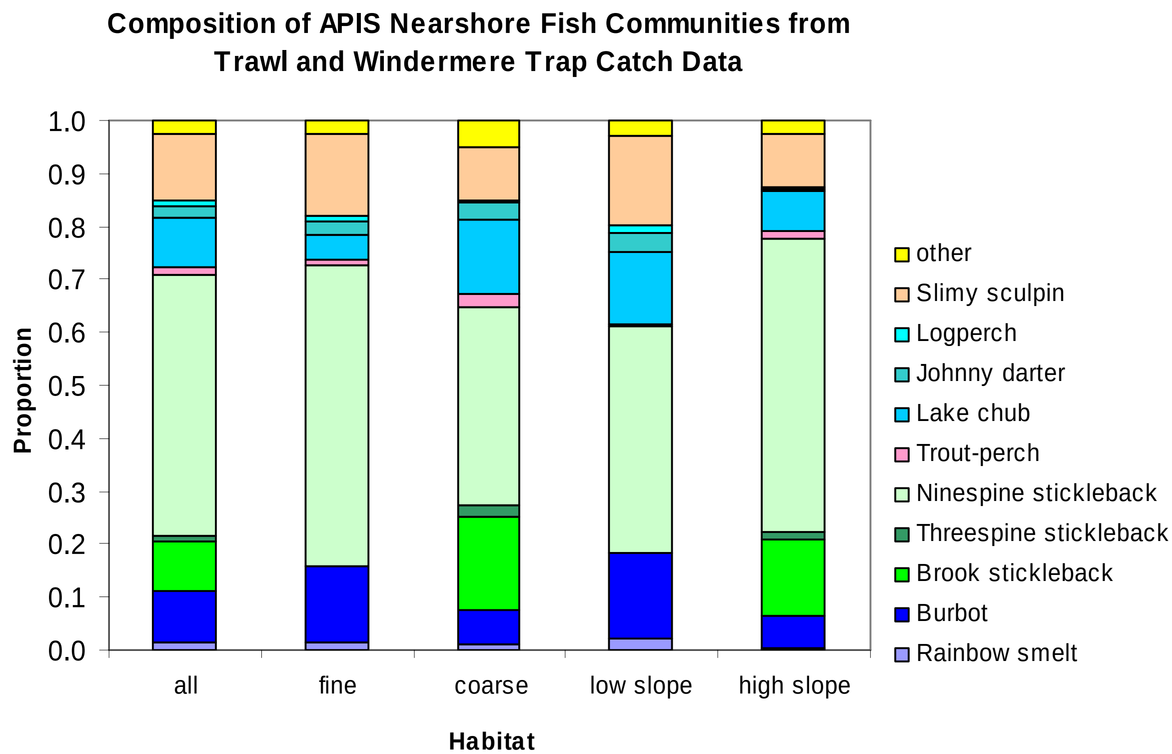


Figure 8. Composition of nearshore fish communities in the Apostle Islands using *Adjusted Species Abundance* for combined samples to generate composites from 5.2 m bottom trawl tow and Windermere trap data, 2003-2004. “All” represents the overall composition from all sites sampled. Fine and coarse represent habitats by average substrate composition: fine is dominated by sand and small gravel and coarse is dominated by large gravel, cobble and rock. Mean slopes < 4.2° were classified as “low” and those > 4.2° were classified as “high”.

Comparison of nearshore vs. offshore fish communities at APIS

A comparison of community composition from our nearshore Windermere trap and bottom trawl samples with Yule et al.'s (*in press*) summer offshore bottom and mid-water trawl samples showed changes along a gradient of depth intervals from ≤ 15 m to 120 m (Table 4; Fig. 9). Note that there is a gap in sampling the > 15 m to 30 m depth interval in this series. As noted previously, the nearshore fish community sampled in ≤ 15 m depths was dominated by ninespine stickleback, but slimy sculpin, lake chub, and burbot were also collected in high numbers. In the 30 m depth interval, the community was dominated by slimy sculpin and pelagic species lake whitefish and lake herring, but with increasing depth, abundance of sculpins increased and deepwater sculpin dominated in the deepest depth interval (Table 4; Fig. 9). Only slimy sculpin was an abundant species across all depth intervals.

The USGS spring bottom trawl samples differed from that of Yule et al. (*in press*) in that bottom trawls were towed *cross-contour* to integrate catch from a starting depth of ~15 m to an ending depth of ~80 m. As a result, USGS spring bottom trawl data could not be subdivided into depth bins but represented a composite representation of the entire offshore fish community. Composition of spring bottom trawl catches was very different from Yule et al.'s summer trawl catches; spring trawl catches were strongly dominated by coregonids (lake whitefish, lake herring, bloater) and rainbow smelt (Table 4; Fig. 9). The differences in catch composition are likely the result of seasonal changes in habitat associations in offshore fishes and the lack of mid-water trawl samples in the spring. We also note that in spring 2004, yearling lake herring were very abundant in spring bottom trawl samples, which was a reflection of a strong 2003 year class of lake herring (Stockwell et al. 2005).

Summary—APIS nearshore fish community and habitat associations

In summary, we found the nearshore fish community of the Apostle Islands to be dominated by few species (ninespine stickleback, brook stickleback, slimy sculpin, lake chub, and burbot). The predominant nearshore habitat of the APIS region was characterized by low slope with sandy substrates. Most margins of the islands were unprotected from the open lake and subject to regular wave action which created a cobble-pebble-gravel band of substrate out to ~1 m depth. Beyond this surf zone, aquatic macrophytes were abundant in some areas. Some islands had shorelines of exposed sedimentary sandstone with nearshore zones dominated by rugged boulder and sandstone bedrock substrates. In areas of fine substrates, the community was dominated by ninespine stickleback but as slope and substrate size increased, slimy sculpin, burbot, lake chub, and brook stickleback became co-dominant with ninespine stickleback. In areas with coarse substrates (boulder-bedrock), lake chub was the predominant species. We found the structure of the offshore fish community to be distinct from that of the nearshore community. The offshore community was dominated by coregonids and sculpins and only the slimy sculpin held a position of strong relative importance in both communities. The lake chub was the most distinctive feature of the nearshore fish community as it was both unique to nearshore waters and was an abundant, conspicuous member of that community.

Table 4. Summary of APIS nearshore and offshore fish sampling data, 2003-2004. Shown are summary catches for 2003-2004 USGS sampling effort in the Apostle Islands: Windermere traps and 5.2 m bottom trawl (nearshore), spring cross-contour 12 m bottom trawl (spring BT), combined offshore mid-water trawl (MT) and bottom trawl (BT) targeted depth catch (offshore BT and MT). All data are expressed as number of fish per hectare (ha) except for Windermere traps, which is expressed as number/array/day. Windermere traps were set in arrays of 12 (see Methods). Spring BT catch data were obtained from USGS, Lake Superior Biological Station, Ashland, Wisconsin and offshore MT and BT targeted depth data were from Yule et al. (*in press*). Locations for USGS spring BT samples are listed in Table 1.

		Nearshore sampling		**Offshore sampling**				
		Trap Array	**5.2 m BT**	**Spring BT**	**Offshore BT and MT**			**Offshore**
	Species	**<15 m**	**<15 m**	**15-100 m**	**30 m**	**60 m**	**120 m**	**Total**
1	Alewife			<0.0				
2	Rainbow smelt		11.7	67.1	54.4	13.2	4.5	72.2
3	Burbot	4.1	2.6	0.1	23.1	4.3	1.9	29.4
4	Brook stickleback	4.0	0.4					
5	Threespine stickleback	0.4				1.0		1.0
6	Ninespine stickleback	5.4	418.0	24.9	8.2	4.2	1.4	13.8
7	Trout-perch	0.5	5.8	21.7	1.2			1.2
8	Lake herring		0.4	254.7	194.1	97.2	22.2	313.6
9	Lake whitefish		0.7	114.5	669.6	50.8	1.7	722.2
10	Bloater			82.5	7.1	9.4	7.9	24.5
11	Kiyi			0.1	5.0	6.3	5.4	16.7
12	Shortjaw cisco						0.4	0.4
13	Pygmy whitefish			0.5	2.0	4.6		6.6
14	Round whitefish		2.2	0.2				
15	Lean lake trout			0.8	11.7	5.1	1.9	18.7
16	Siscowet lake trout			0.1	9.2	1.1		10.3
17	Longnose sucker	0.1			37.3			37.3
18	White sucker	0.2	0.7					
19	Lake chub	4.0						
20	Blacknose dace	0.2						
21	Longnose dace		0.4					
22	Rockbass	0.1						
23	Johnny darter	0.1	19.0	0.2	1.2			1.2
24	Logperch	0.1	9.1					
25	Ruffe		0.4	<0.0		0.6		0.6
26	Mottled sculpin	0.2						
27	Slimy sculpin	5.2	21.9	3.5	699.7	162.8	205.1	1067.5
28	Spoonhead sculpin	0.1	3.3	1.6	61.0	27.6	180.0	268.6
29	Deepwater sculpin			1.9	9.7	61.8	901.6	973.1
	Grand Total	**24.6**	**496.6**	**574.7**	**1794.5**	**450.2**	**1334.1**	**3578.8**

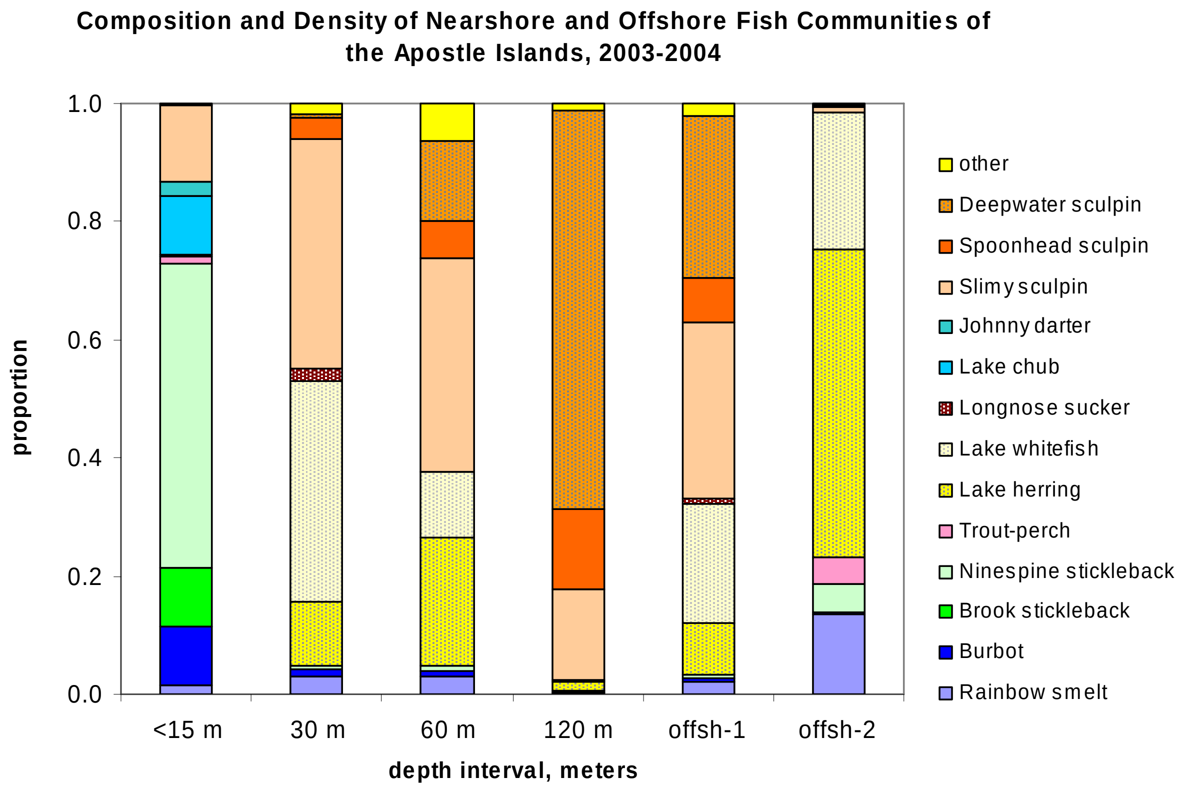


Figure 9. Composition of fish communities of the nearshore and offshore zones in the Apostle Islands, 2003-2004. The nearshore community is represented by a composite of data from all sites sampled with Windermere traps and 5.2 m bottom trawls (Fig. 8). Depth intervals 30, 60, and 120 m represent offshore community composition from 12 m bottom and 17 m mid-water trawl samples taken in summer 2004 (Yule et al. *in press*). Offsh-1 is the composite of the summer 2004 offshore samples. Offsh-2 represents a composite of spring offshore bottom trawl samples taken in 2003 and 2004 in the Apostle Islands by USGS, Lake Superior Biological Station, Ashland, Wisconsin. The USGS spring offshore trawl samples covered a ~15-80 m depth interval.

Isle Royale National Park

Species inventory

During 2004, we set arrays of Windermere traps over 25 sample locations and set fyke nets at 58 sample locations, all distributed across seven major embayments of ISRO (Fig. 3, 10-13; Tables 5-6; Append. C-F). Fyke nets yielded 18 fish species while Windermere trap arrays yielded a subset of 10 species (Table 5). Of these species, lake chub, trout-perch, slimy sculpin, nine-spine stickleback, white sucker, and burbot were the most abundant (Fig. 14; Append. E-F).

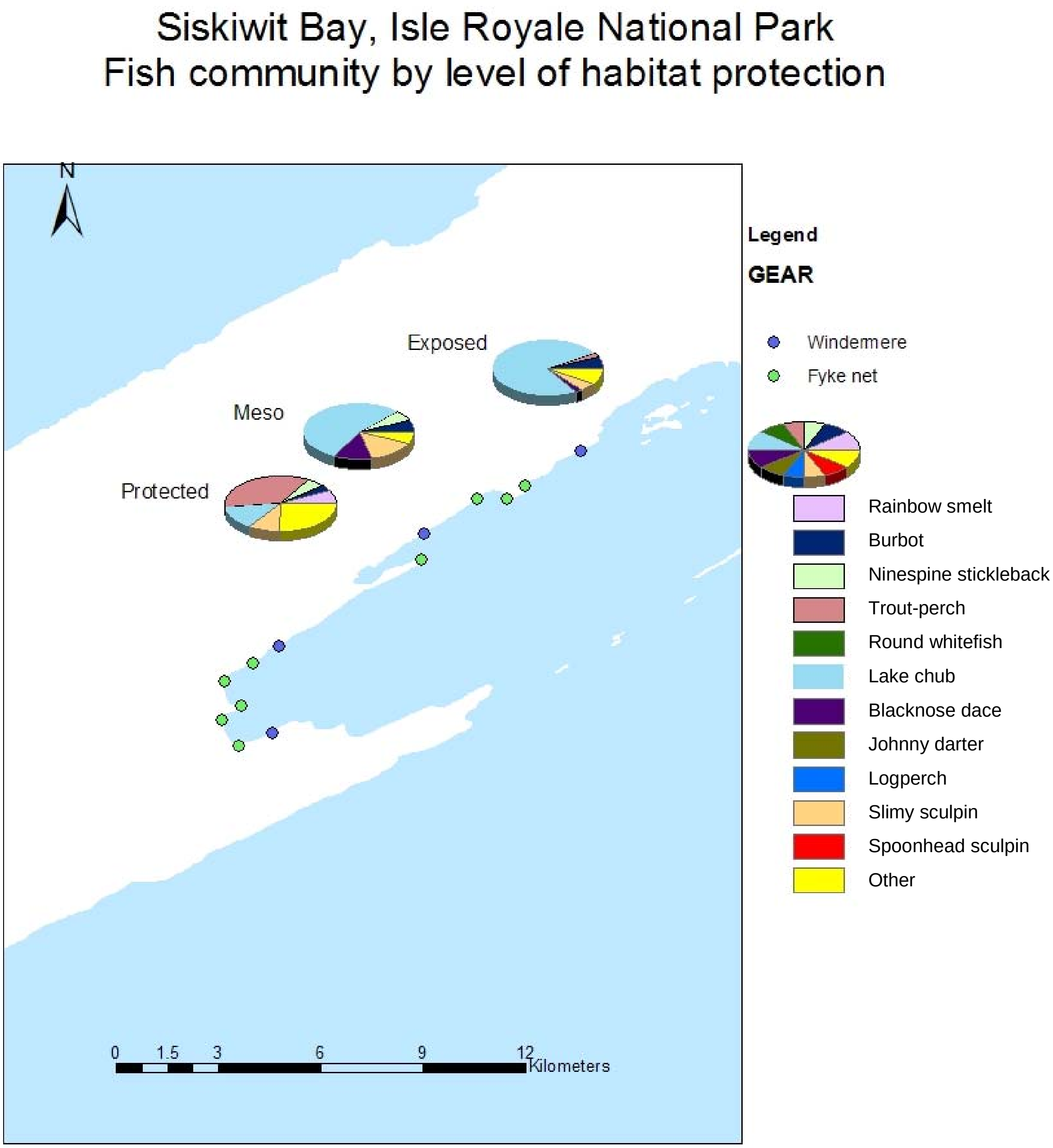


Figure 10. Windermere trap and fyke net sampling locations in Siskiwit Bay, Isle Royale, 2004. Pie diagrams show composition of a composite of Windermere trap and fyke net catches from areas of high, intermediate, and low protection. Protection levels derived from EEI (embayment exposure index): low (exposed to open lake) < 4.0; intermediate (meso) 4.0-7.0; high (protected) > 7.0.

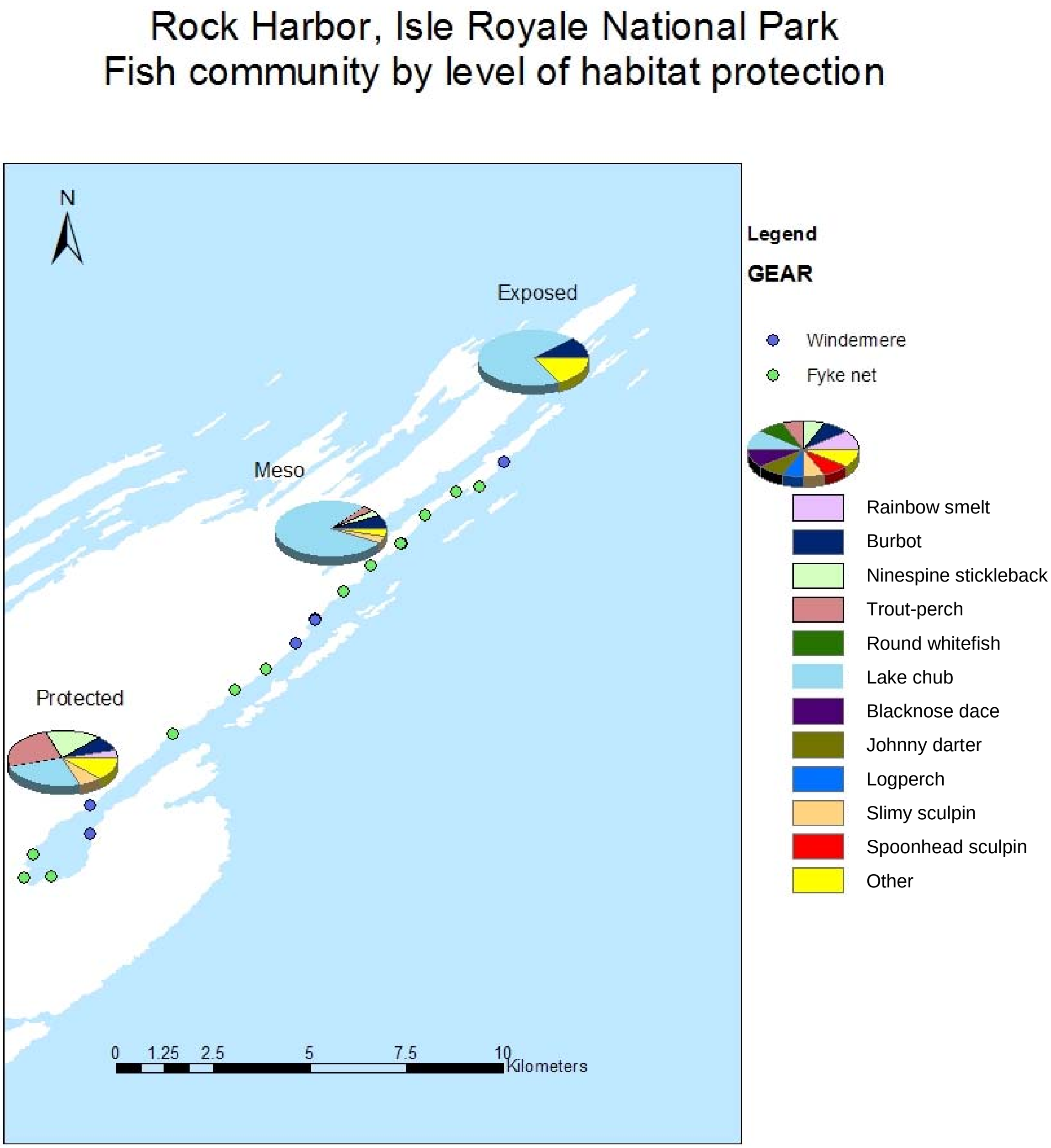


Figure 11. Windermere trap and fyke net sampling locations in the Rock Harbor embayment, Isle Royale, 2004. Pie diagrams show composition of a composite of Windermere trap and fyke net catches from areas of high, intermediate, and low protection. Protection levels derived from EEI (embayment exposure index): low (exposed to open lake) < 4.0; intermediate (meso) 4.0-7.0; high (protected) > 7.0.

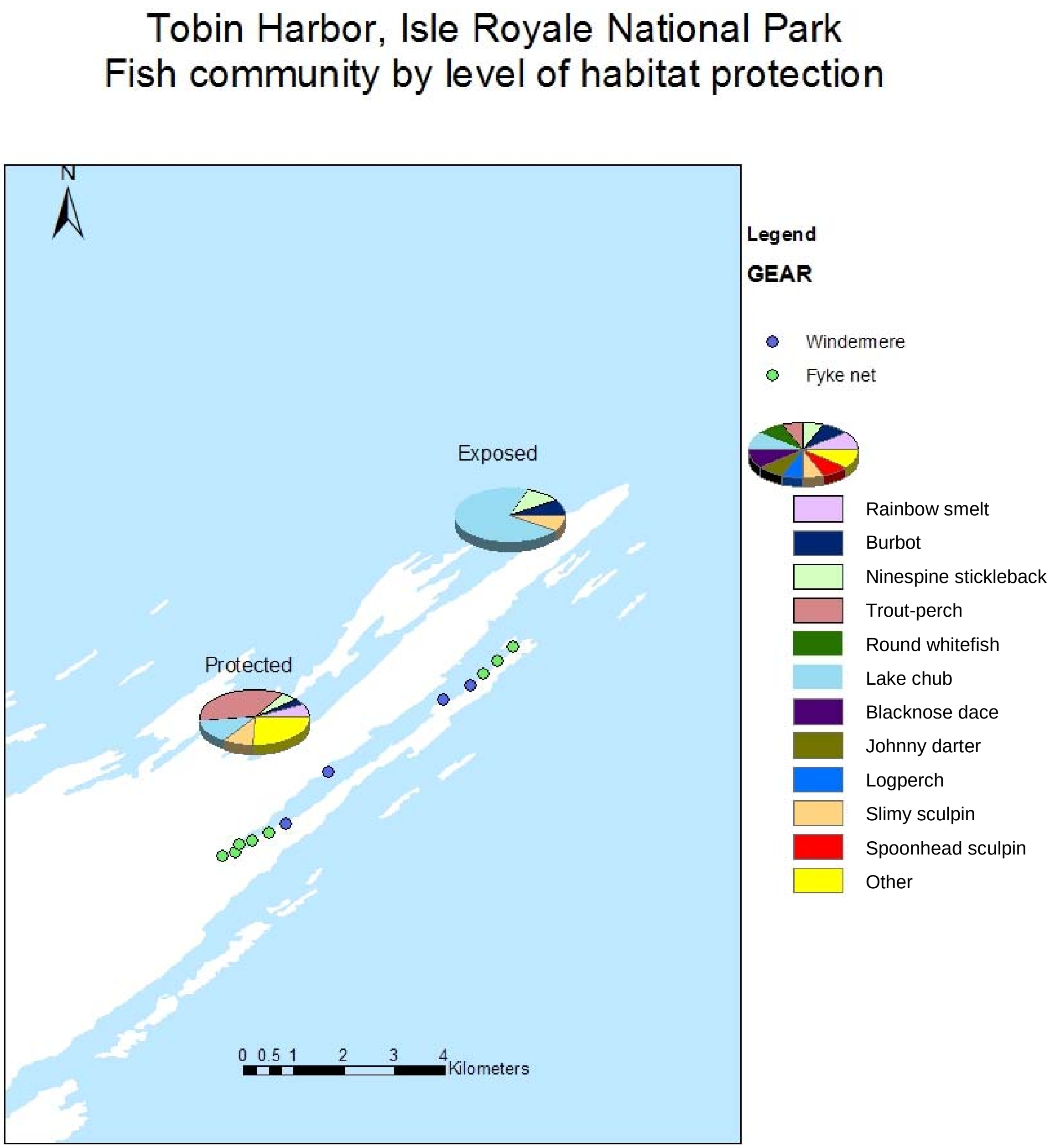


Figure 12. Windermere trap and fyke net sampling locations in Tobin Harbor, Isle Royale, 2004. Pie diagrams show composition of a composite of Windermere trap and fyke net catches from areas of high and low protection. Protection levels derived from EEI (embayment exposure index): low (exposed to open lake) < 4.0; high (protected) > 7.0.

Robinson Bay, Isle Royale National Park
Fish community by level of habitat protection

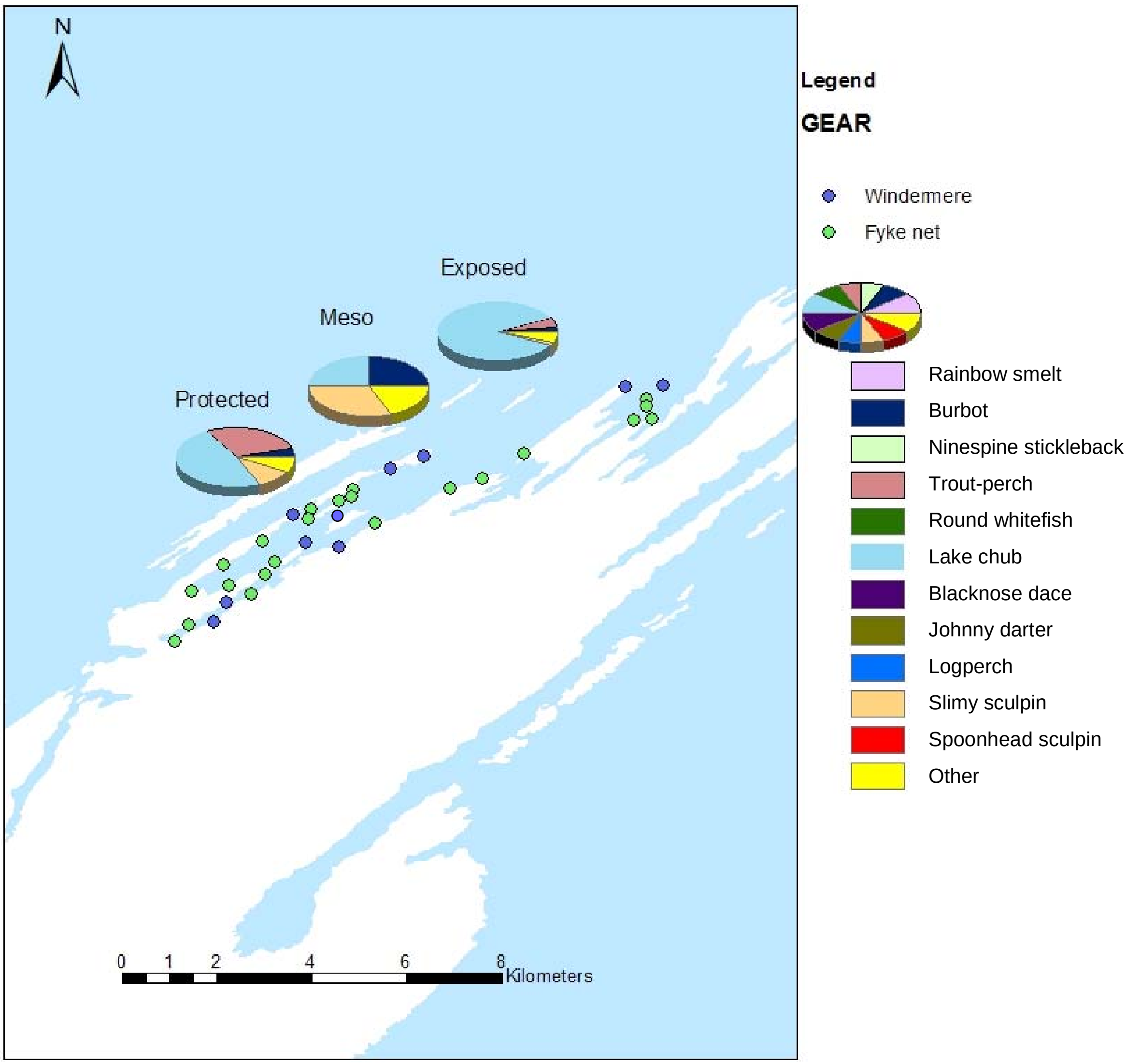


Figure 13. Windermere trap and fyke net sampling locations in the Robinson Bay area of Isle Royale, 2004. Embayments included are Five Finger Bay, Lane Cove, Robinson Bay, and Pickerel Cove. Pie diagrams show composition of a composite of Windermere trap and fyke net catches from areas of high, intermediate, and low protection. Protection levels derived from EEI (embayment exposure index): low (exposed to open lake) < 4.0; intermediate (meso) 4.0-7.0; high (protected) > 7.0.

Table 5. Species captured in nearshore waters of ISRO during 2004. Colors are used to identify species in figures. Great Lakes fish taxocenes: 1 = coastal, 2 = intermediate, 3 = open-water (Wei et al. 2004). Thermal groups: 1 = cold, 2 = cold-cool, 3 = cool, 4 = cool-warm, 5 = warm (Coker et al. 2001; Wei et al. 2004).

	Common Name	Scientific Name	Abbr	Color	Windermere trap	Fyke net	Taxocene	Thermal Group
1	Rainbow smelt	*Osmerus mordax*	RNS			X	2	1
2	Burbot	*Lota lota*	BRB		X	X	3	1
3	Brook stickleback	*Culaea inconstans*	BKS		X	X	1	3
4	Ninespine stickleback	*Pungitius pungitius*	NSS		X	X	3	1
5	Trout-perch	*Percopsis omiscomaycus*	TRP		X	X	2	1
6	Lake herring	*Coregonus artedi*	LKH		X	X	3	1
7	Lake Whitefish	*Coregonus clupeaformis*	LWF			X	3	1
8	Brook trout	*Salvelinus fontinalis*	BRT			X	3	1
9	Longnose sucker	*Catostomus catostomus*	LNS		X	X	3	1
10	White sucker	*Catostomus commersoni*	WHS		X	X	2	3
11	Emerald shiner	*Notropis atherinoides*	EMS			X	2	3
12	Spottail shiner	*Notropis hudsonius*	STS			X	2	2
13	Bluntnose minnow	*Pimephales notatus*	BNM			X	1	5
14	Longnose dace	*Rhinichthys cataractae*	LND			X	2	3
15	Lake chub	*Couesius plumbeus*	LKC		X	X	3	1
16	Blacknose dace	*Rhinichthys atratulus*	BND		X	X	1	3
17	Slimy sculpin	*Cottus cognatus*	SLS		X	X	3	1
18	Spoonhead sculpin	*Cottus ricei*	SPS			X	3	1
					10 spp	18 spp		

Table 6. Species richness (number of species) and species diversity (H´) measures for ISRO Windermere trap and fyke net samples, 2004. Species diversity is expressed as the Shannon index (H´; Shannon and Weaver 1949). The antilog of H´ (exp H´) represents the number of equivalent or co-dominant species. Samples refer to number of individual trap or net sets, sites refer to number of locations were arrays of traps or individual fyke nets were deployed, and N refers to the total number of fish caught. All gear was set for 24 hours. Diversity values in red indicate the four most diverse local communities for each gear type.

Windermere traps	number					
	samples	sites	species	individuals	H'	EXP(H')
all	300	25	10	839	1.371	3.937
low slope	180	15	8	290	1.533	4.632
high slope	120	10	10	549	1.089	2.971
low protect	144	12	9	532	1.036	2.819
interm protect	84	7	9	147	1.687	5.402
high protect	72	6	6	160	1.402	4.063
fine substrate	48	4	8	92	1.525	4.597
interm substrate	96	8	9	301	1.286	3.617
coarse substrate	156	13	8	446	1.159	3.188

Fyke nets	number					
	samples	sites	species	individuals	H'	EXP(H')
all	58	58	18	2166	1.168	3.215
low slope	23	23	16	981	1.242	3.463
high slope	25	25	13	1185	1.039	2.827
low protect	23	23	13	1241	0.518	1.679
interm protect	20	20	14	455	1.147	3.149
high protect	15	15	11	470	1.801	6.059
fine substrate	10	10	12	514	1.461	4.311
interm substrate	23	23	14	941	1.079	2.942
coarse substrate	25	25	12	711	0.826	2.284

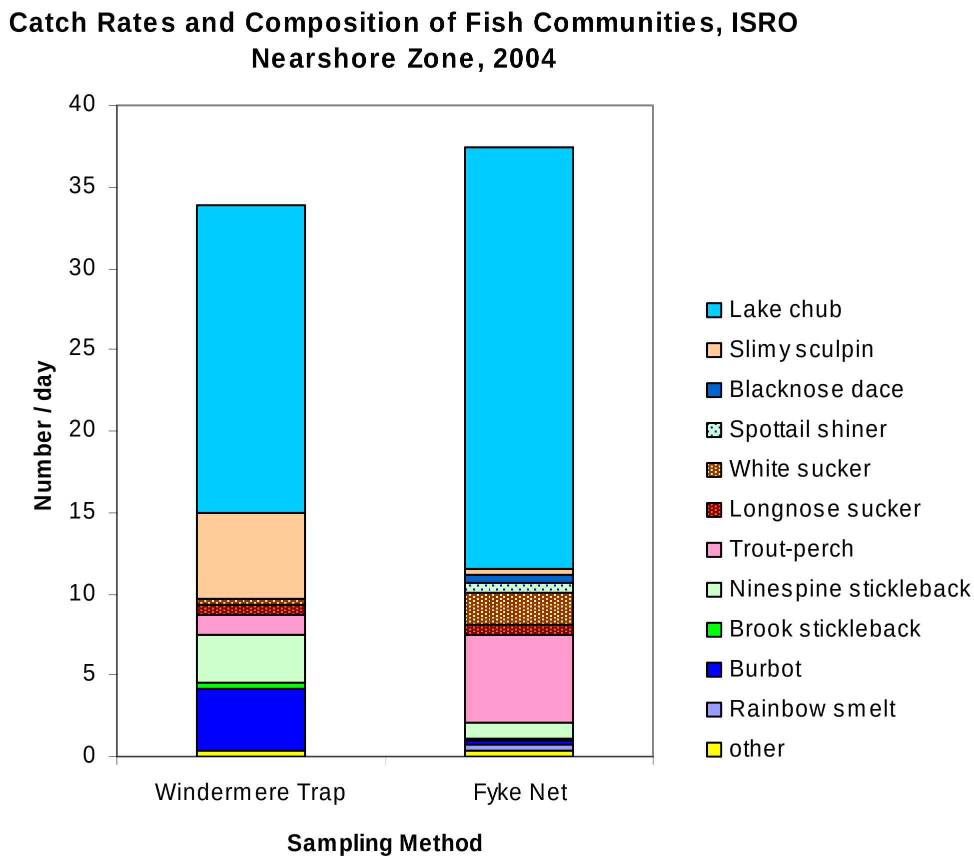


Figure 14. Comparison of catch rates and composition of nearshore fish communities from Windermere trap arrays and fyke net sets in nearshore waters of Isle Royale National Park, 2004.

Comparison of sampling methods

Both Windermere traps and fyke nets were used successfully in all nearshore habitat types and sampled the same communities across a similar array of habitats (Table 6; Append. C, D). The pairing of these two sampling methods in embayments and across habitat types permitted evaluation of their relative abilities to reveal community structure. Fyke net catches yielded more species than Windermere traps (18 vs. 10; Fig. 14; Table 5; Append. E-F). Catches from Windermere traps returned higher overall and average H′ diversity than fyke nets over the range of nearshore habitats sampled (1.371 vs. 1.168 and 1.343 vs. 1.142, respectively; Table 6). Lake chub was the dominant species in both fyke net and trap catches, but composition differed substantially; overall, composition was only 67% similar (Table 7). In addition to lake chub, trout-perch and white sucker were the second and third most abundant species in total fyke net catch, while slimy sculpin, burbot, ninespine stickleback and trout perch were the predominant species in Windermere trap catches (Fig. 14; Append. E-F). There were no unique species to Windermere traps but eight species were unique to fyke nets: rainbow smelt, lake whitefish, brook trout, emerald shiner, spottail shiner, and bluntnose minnow (Table 5).

Fish community structure and habitat associations

Windermere trap catch data partitioned by nearshore habitat characteristics (gradient/slope, substrate, and protection from the open lake) reflected differences in community composition by habitat (Tables 6, 7; Figs. 15-17). Composition, relative abundance, and PS measures from Windermere trap catches showed considerable difference among sites with high and low slope and fine to coarse substrate. For example, PS of catch composition conditioned by substrate type ranged from 0.41-0.52 (mean = 0.45), which suggests that community composition was associated with distinct substrate categories (Table 7). Between sites with high and low gradient, PS was 0.56, again suggesting that communities in these two types of habitat were relatively distinct. PS values for trap catches from low, meso (intermediate), and high protection as reflected in EEI, were higher, ranging 0.49-0.71 (mean = 0.58). However, when the comparison is limited to low vs. high protection and meso vs. high protection, PS was lower (0.54, 0.49 respectively), suggesting that community composition in areas of high protection was relatively distinct from those in areas of low and meso protection. Catch composition from areas of low and meso protection were more similar (0.71).

Table 7. Similarity (PS) matrices for nearshore fish communities of ISRO by gear and habitat characteristics. The ALL category provides a comparison with the average community composition over all sites. Under *Summary of Similarities*, the average similarities for each habitat grouping are shown. *Gear comparison* shows the level of agreement of community composition for different habitat types and ALL provides a measure of overall agreement in estimating community composition. Values in red indicate very low similarity (< 60%), values in orange indicate low similarity (< 70%), and values in blue indicate high similarity (> 85%).

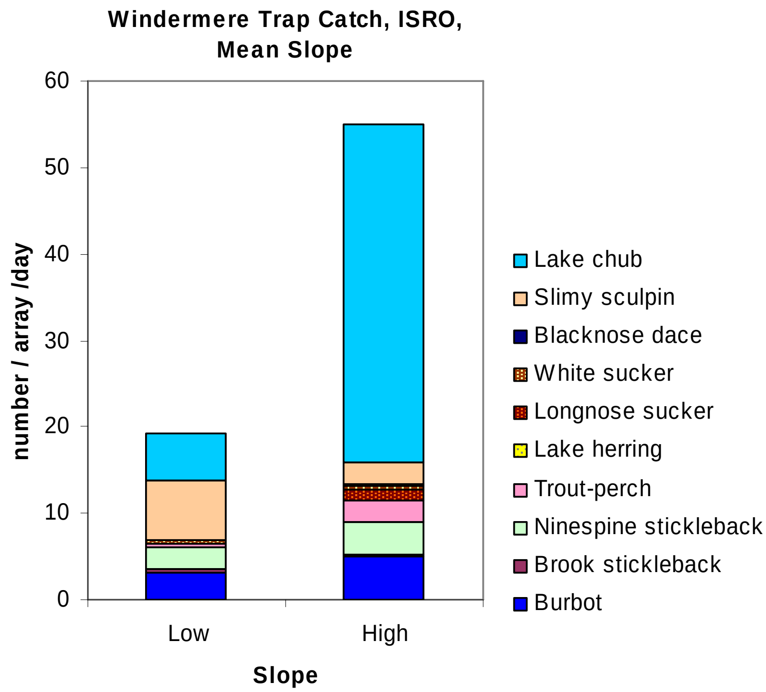
Fyke nets		**substrate**			**gradient**		**protection**			
		fine	intermd	coarse	low	high	low	meso	high	ALL
substrate	fine	1.00								
	intermed	0.74	1.00							
	coarse	0.62	0.83	1.00						
gradient	low	0.78	0.92	0.81	1.00					
	high	0.73	0.92	0.85	0.87	1.00				
protection	low	0.57	0.80	0.92	0.74	0.82	1.00			
	meso	0.78	0.89	0.78	0.92	0.89	0.74	1.00		
	high	0.68	0.45	0.34	0.50	0.44	0.27	0.47	1.00	
	ALL	0.77	0.95	0.84	0.93	0.94	0.79	0.91	0.47	1.00

Windermere traps		**substrate**			**gradient**		**protection**			
		fine	intermd	coarse	low	high	low	meso	high	ALL
substrate	fine	1.00								
	intermed	0.52	1.00							
	coarse	0.41	0.41	1.00						
gradient	low	0.78	0.67	0.58	1.00					
	high	0.36	0.82	0.88	0.56	1.00				
protection	low	0.37	0.81	0.90	0.54	0.92	1.00			
	meso	0.65	0.58	0.57	0.82	0.51	0.49	1.00		
	high	0.71	0.72	0.59	0.80	0.54	0.54	0.71	1.00	
	ALL	0.52	0.89	0.89	0.69	0.84	0.83	0.65	0.69	1.00

Summary of Similarities

	substrate	**gradient**	**protection**	**substr-gradient**	**substr-grad-protect**	**ALL**
Windermere traps	0.45	0.56	0.58	0.60	0.63	0.75
Fyke nets	0.73	0.87	0.49	0.81	0.72	0.82

GEAR Comparison	**substrate**			**gradient**		**protection**			
	fine	intermd	coarse	low	high	low	meso	high	ALL
Windermere traps vs. Fyke nets	0.19	0.63	0.75	0.35	0.81	0.79	0.42	0.27	0.67



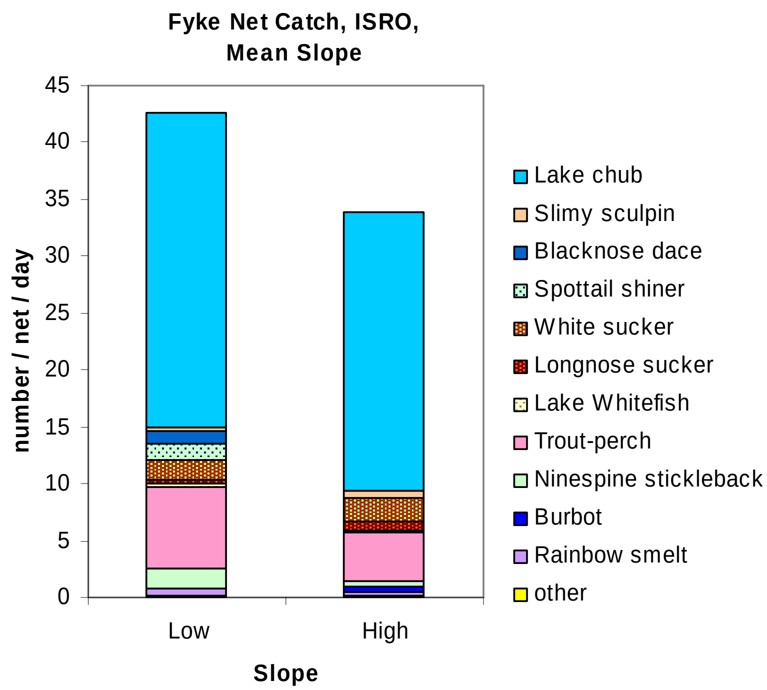
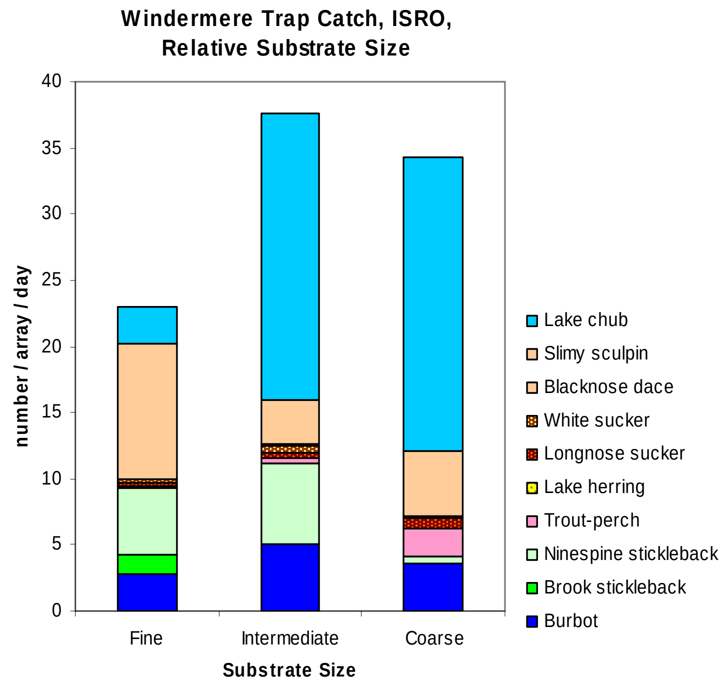


Figure 15. Comparison of catch rates and composition of nearshore fish communities from Windermere trap and fyke net catches in low- and high slope nearshore waters of Isle Royale National Park, 2004. Mean slopes > 4.2° were classified as "high" and those < 4.2° were classified as "low".



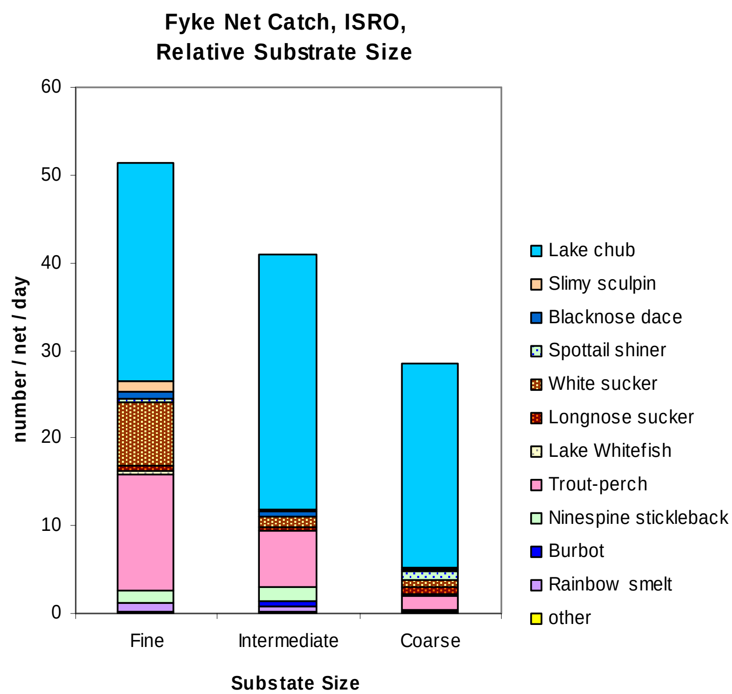


Figure 16. Comparison of catch rates and composition of nearshore fish communities from Windermere trap and fyke net catches in nearshore waters of Isle Royale National Park, 2004, with fine, intermediate and coarse substrates. Range of mean substrate sizes (modified Wentworth scale) were fine 0-3.0 (silt to small gravel); intermediate > 3.0-5.0 (large gravel to small cobble); coarse > 5.0 (large cobble to bedrock).

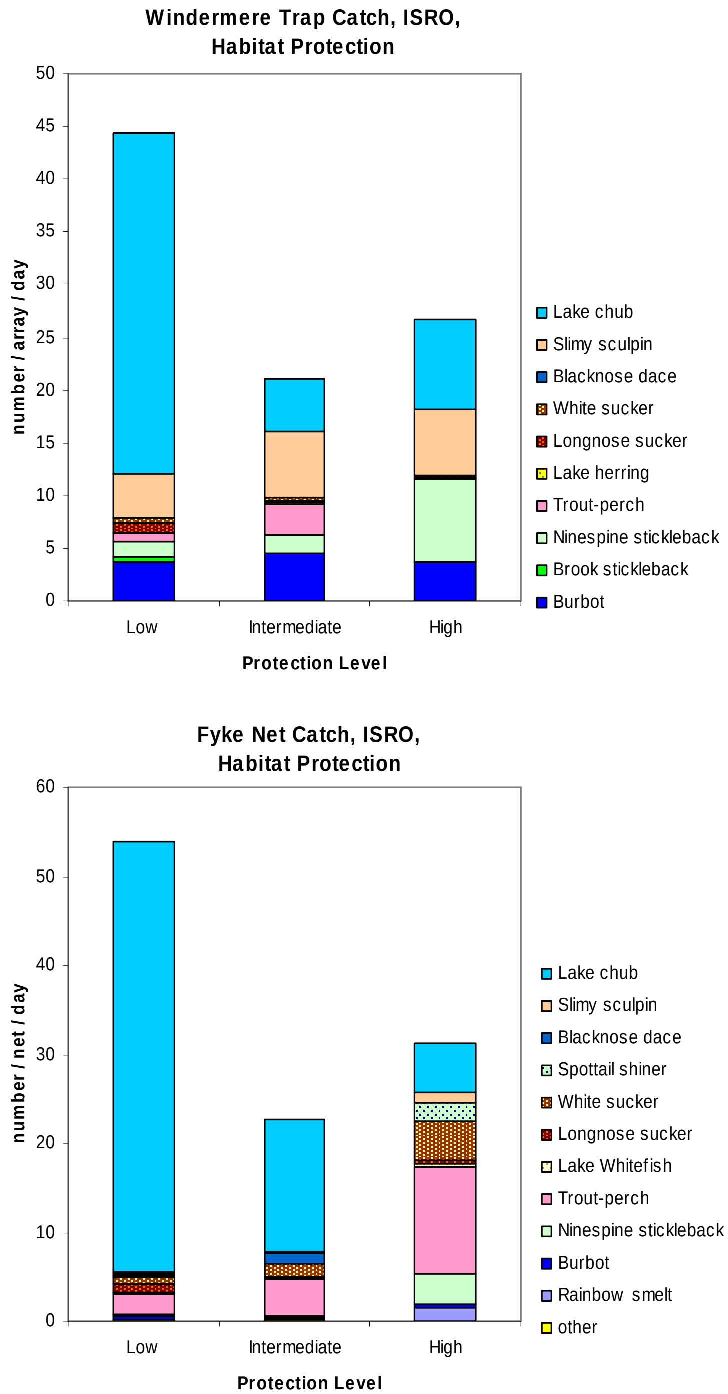


Figure 17. Comparison of catch rates and composition of nearshore fish communities from Windermere trap and fyke net catches in nearshore waters of Isle Royale National Park, 2004, with low, intermediate and high protection. Protection levels derived from EEI (embayment exposure index): low < 4.0; intermediate (meso) 4.0-7.0; high > 7.0.

Comparisons of Windermere trap catch composition from areas conditioned by a combination of substrate size, gradient and protection revealed further details in patterns of habitat associations (Table 7). For example, PS values that compare catch composition from areas of high and low gradient vs. substrate size suggest that areas of low slope were associated with fine substrate and areas of high slope were associated with coarse substrates: the greatest differences (lowest PS) were between catches from areas of low slope and coarse substrates and high slope and fine substrates (0.58, 0.36, respectively), and the greatest similarities were between areas with low slope and fine substrates (PS = 0.78) and areas with high slope and coarse substrates (PS = 0.88). Catches from areas characterized by intermediate substrate size were more similar to those from high gradient than from low gradient areas (0.82, 0.67, respectively). Comparison of catches from areas of high, meso, and low protection with those with various categories of gradient and substrate showed that catches from areas of low protection were distinct from those of fine substrate (0.37) and were associated with coarse and intermediate substrates and high gradient (PS = 0.90, 0.81, 0.92, respectively). In contrast, catches from areas of high protection were relatively distinct from those with coarse substrates (0.59) and were associated with fine and intermediate substrates and low slope (PS = 0.71, 0.72, 0.80, respectively). Taken together, the PS analysis of Windermere trap catches suggests that areas of high protection at the heads of bays were associated with low slopes and fine substrates and areas of low protection at the mouth of bays were associated with higher slopes and coarse substrates.

Fyke net catch data partitioned by nearshore habitat characteristics reflected fewer differences in community composition by habitat than Windermere trap catch data (Tables 6, 7; Figs. 15-17). Species composition, relative abundance, areal density estimates and PS measures from fyke net catches showed less difference among sites with high and low slope and fine to coarse substrate (Table 7). Composition of catches from areas of different substrate size were not as distinct (PS ranged 0.62-0.83), nor were catches from low and high gradient (0.87), but like Windermere trap catches, fyke net catches from low and high protection were relatively distinct (0.27). And like Windermere trap catches, fyke net catches from areas of meso protection were more similar to those in low protection (PS = 0.74) than high protection (0.47). As might be expected from these results, comparisons of fyke net catches conditioned by a combination of substrate size and gradient were generally less distinct than those from Windermere trap catches (PS ranged 0.73-0.92). However, comparison of catches from areas of high, meso and low protection with those with various gradient and substrate types showed similar results to those from Windermere trap catches. Areas of low protection were distinct from those of fine substrate (PS = 0.57) and were associated with coarse and intermediate substrates and high gradient (PS = 0.92, 0.80, 0.82, respectively). In contrast, catches from areas of high protection were relatively distinct from those with coarse and intermediate substrates (PS = 0.34, 0.45, respectively) and had higher association with fine substrates (PS = 0.680). Unlike comparisons with Windermere trap catches, fyke net catches from areas of high, meso and low protection showed similar levels of differentiation from areas of low and high gradient; community composition from areas of low protection and low and high gradient were relatively similar (PS = 0.74, 0.82, respectively) while composition was relatively distinct between high protection and low and high gradient (0.50, 0.44, respectively). We suspect that differences in catch composition between Windermere traps and fyke nets were caused by differences in the relative catchability of various fish species by each gear.

The patterns of similarities just discussed show that Windermere traps could discriminate community composition across a broad array of habitat types: areas of high and low protection, fine to coarse substrates, and high and low slope. The pattern of similarities in Table 7 also identifies relatively distinct fish community compositions that were associated with distinct combinations of habitat characteristics: areas of high protection, low slope and fine substrates near the head of embayments vs. areas of low protection, high slope and coarse substrates near the mouth of embayments. Areas of intermediate protection with varying slope and substrate found in the middle portion of embayments had intermediate community composition. In areas of low protection near the mouth of embayments, the catch composition was dominated by lake chub, and was reflected in low species diversity ($H' = 1.036$; Table 6; Fig. 17). In areas of high and meso protection, the catch composition was more diverse and was reflected in higher species diversity ($H' = 1.687$, 1.402, respectively). Important species in habitats of high and meso protection included: lake chub, slimy sculpin, ninespine stickleback, and burbot (Fig. 17).

Unlike Windermere traps, fyke nets could only clearly discriminate community composition between areas of low and high protection. As shown with Windermere trap catches, community composition in areas of low protection was strongly dominated by one species, lake chub, and was reflected in the lowest measured species diversity ($H' = 0.518$; Table 6; Fig. 17). Also like Windermere trap catches, there was a more diverse assemblage of species in catches from highly protected habitats and was reflected in the highest measured species diversity ($H' = 1.801$). However, the catch composition of important species in protected habitats was different and included lake chub, trout-perch, white sucker, ninespine stickleback, spottail shiner, and rainbow smelt (Fig. 17).

Fish-habitat associations and life stage

Partitioning Windermere trap catch data into adult and juvenile subsets showed differences in habitat association by life stage. Catch composition of adults and juveniles varied with protection level and substrate size (Figs. 18-19). Overall, relative abundance of adults was greater than juveniles (approx. 2x), but both juveniles and adults reached maximal abundance in areas of low protection and coarse substrates. This pattern was largely driven by the dominance of lake chub in both juvenile and adult fractions of the catches. For adults, the proportion of ninespine stickleback and slimy sculpin increased with increasing protection while that of lake chub decreased. The proportion of adult trout-perch was greatest in areas of intermediate protection while adult burbot were most abundant in areas of low and intermediate protection. For juveniles, lake chub and slimy sculpin showed decreasing importance with increasing protection while the proportion of juvenile burbot increased slightly with protection level. As with adults, juvenile trout-perch were most abundant in areas of intermediate protection. Finally, juvenile white- and longnose suckers were most abundant in areas of low protection. Turning to distribution by substrate size, the proportion of adult and juvenile lake chub and the abundances of adults and juveniles of most species increased with substrate size. The exception to this pattern was nine-spine stickleback, which reached maximal abundance in areas with intermediate substrate. Catches from areas of fine substrate had much lower abundance than those with intermediate and coarse substrates; important species in areas with fine substrate included adult and juvenile slimy sculpin, adult ninespine stickleback, and juvenile burbot.

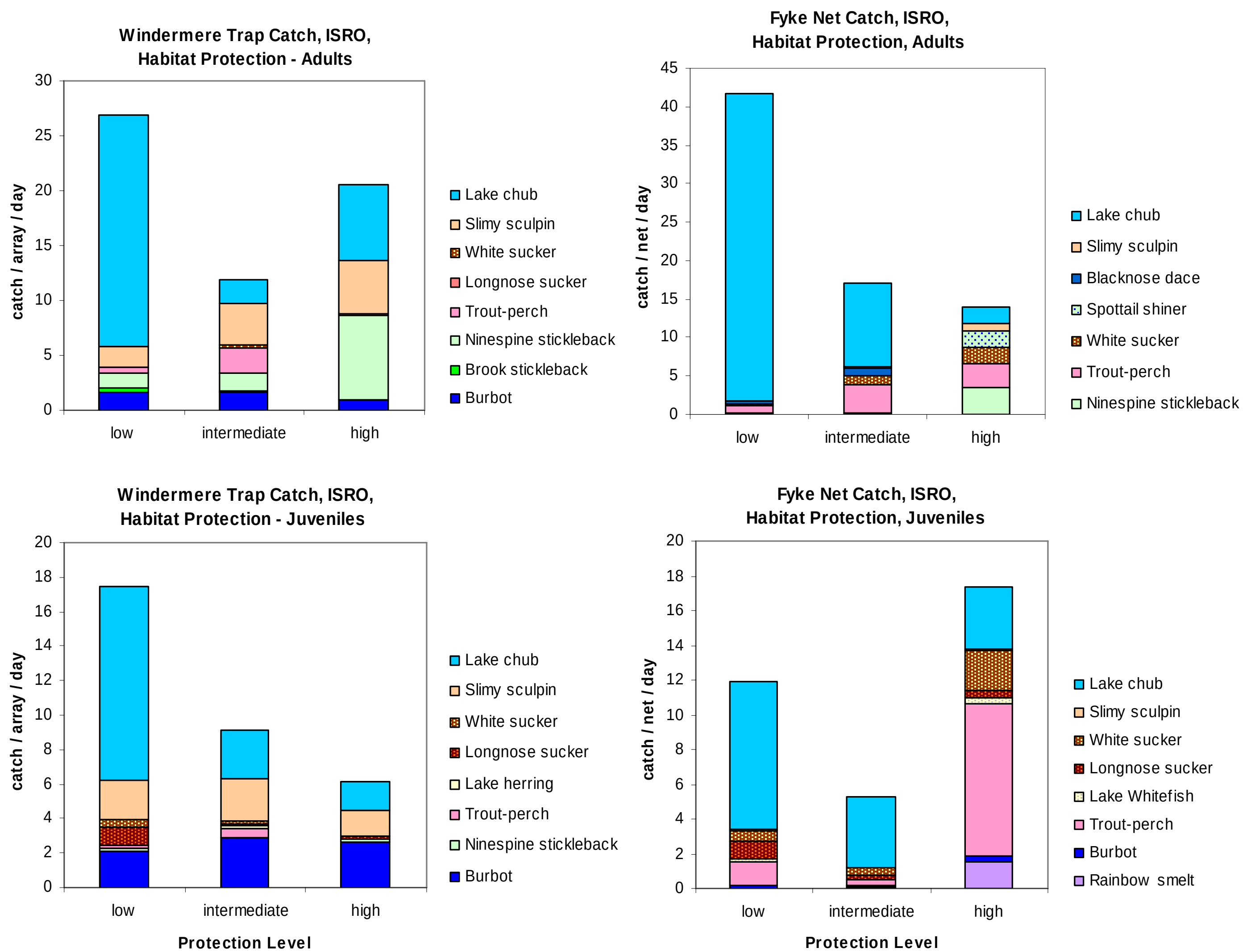


Figure 18. Comparison of catch rates and composition of adult vs. juvenile fishes from Windermere trap and fyke net catches in nearshore waters of Isle Royale National Park, 2004, with low, intermediate and high protection. Protection levels derived from EEI (embayment exposure index): low < 4.0; intermediate 4.0-7.0; high > 7.0.

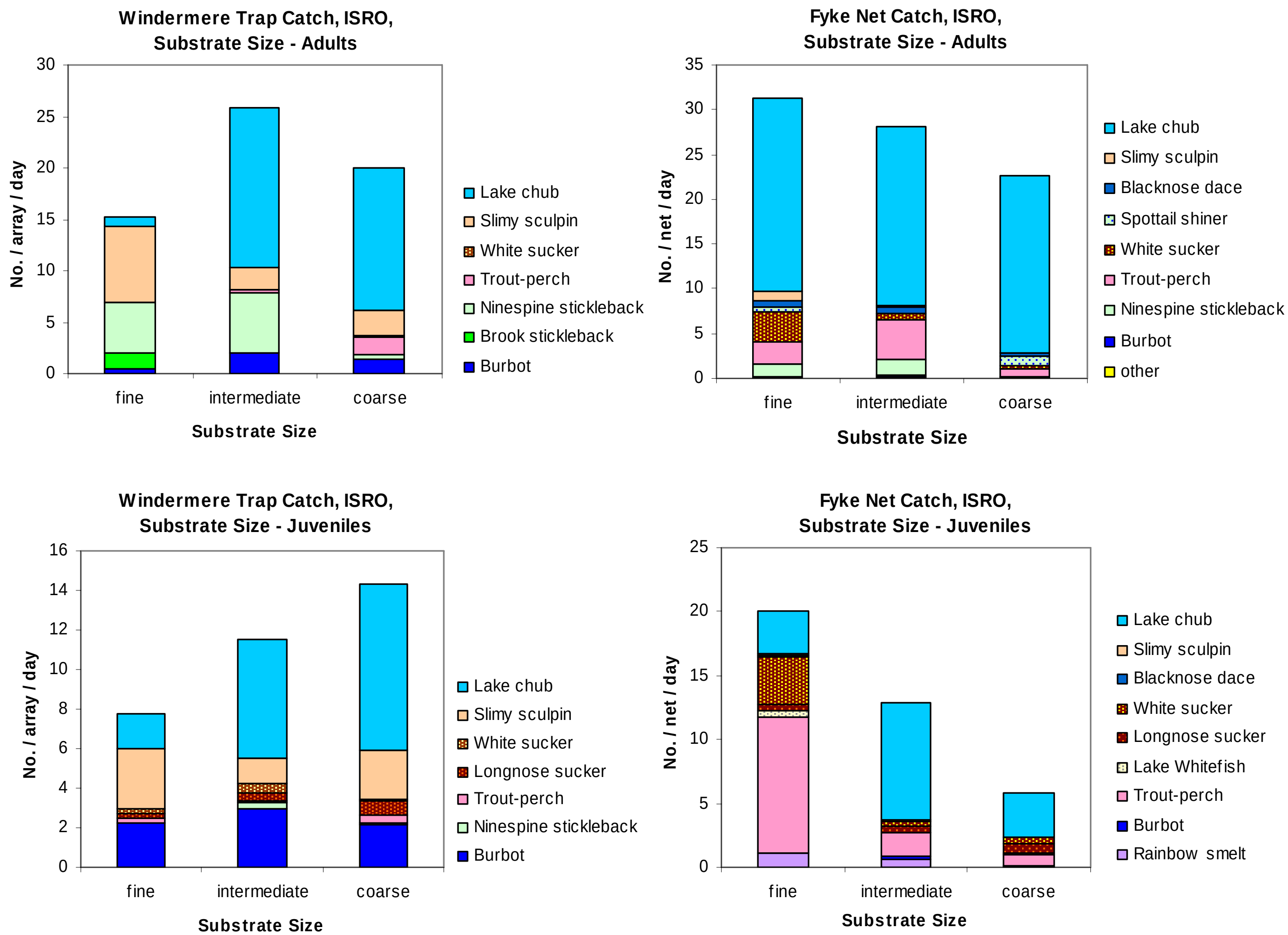


Figure 19. Comparison of catch rates and composition of adult vs. juvenile fishes from Windermere trap and fyke net catches in nearshore waters of Isle Royale National Park, 2004, with fine, intermediate and coarse substrates. Range of mean substrate sizes (modified Wentworth scale) were fine 0-3.0 (silt to small gravel); intermediate > 3.0-5.0 (large gravel to small cobble); coarse > 5.0 (large cobble to bedrock).

As with Windermere trap catch data, partitioning fyke net catch data into adult and juvenile subsets showed differences in habitat association by life stage (Figs. 18-19). As found with Windermere trap catches, adult densities in fyke net catches were greater than juveniles (approx. 2 x), but adults reached maximal abundance in areas of low protection and fine substrates while juvenile abundances peaked in areas of high protection and fine substrates. Although lake chub was the most abundant species overall, adult and juvenile lake chub were not dominant in areas of high protection and juveniles were not dominant in areas with fine substrate. Densities of adult lake chub from fyke net catches decreased strongly with increasing protection just as observed in Windermere trap catches. Countering that trend, abundances of adult ninespine stickleback, trout-perch, white sucker, spottail shiner, and slimy sculpin increased with increasing protection as did abundances of juvenile white sucker, trout perch and rainbow smelt. Abundances of adult ninespine stickleback, trout-perch, white sucker, blacknose dace, and slimy sculpin were higher in fine and intermediate sized substrates. Overall, lake chub dominated catches from areas of low protection and coarse substrates while they did not dominate catches from areas of high protection and fine substrate (with the exception of adult chubs dominating catches from areas of fine substrate). These results suggest that fish communities in areas of high protection harbored more diverse assemblages with larger fractions of juvenile fishes.

The collective results of Windermere and fyke net catch data showed that fish assemblages in areas with low protection and coarse substrates (typically located near the mouth of embayments) were dominated by adult and juvenile lake chubs, adult and juvenile slimy sculpin, adult trout-perch and adult burbot. Areas of high protection with fine substrates (typically found near the head of bays) were dominated by adult and juvenile slimy sculpin, adult ninespine stickleback, juvenile lake chub, and juvenile burbot.

Summary—ISRO nearshore fish community and habitat associations

As a summary analysis of ISRO nearshore fish communities, we combined the catch data from Windermere traps and fyke nets to compare community composition by habitat protection, substrate size, and slope (Fig. 20). As noted previously, the dominant species in nearshore habitats of ISRO was the lake chub, and its predominance in local communities increased with decreasing protection and increasing slope and substrate size, indicating that this species is well adapted to the unprotected habitats near the mouth of embayments and along lake shores of ISRO exposed to the open lake. With increasing protection, and decreasing slope and substrate size found near the head of embayments, the predominance of lake chub was reduced and slimy sculpin, trout-perch, ninespine stickleback, white sucker, burbot, spottail shiner, and rainbow smelt became conspicuous members of the nearshore community.

In summary, we found the nearshore fish community of Isle Royale was dominated by few species: lake chub, slimy sculpin, burbot, ninespine stickleback and trout-perch. The predominant nearshore habitat of Isle Royale was characterized by moderate to steep slope and coarse substrates (cobble to bedrock) and the underlying basalt bedrock. The majority of shorelines were relatively unprotected and exposed to wind and wave action of the open lake. Included in this rugged, rocky shoreline were embayments of varying length and width that offered varying levels of protection from the open lake. Within these embayments nearshore habitats varied greatly in slope and substrate composition. Typically at the head of these embayments, nearshore habitat was highly protected and characterized by low slopes and fine to mixed substrates. Fish communities in these highly protected habitats in ISRO consisted of a diverse array of common species that included lake chub, slimy sculpin, trout-perch, ninespine stickleback, burbot, white sucker, and spottail shiner. The unprotected habitat of ISRO was characterized by moderate to high slopes and coarse substrates and lake chub was the dominant species in the fish community.

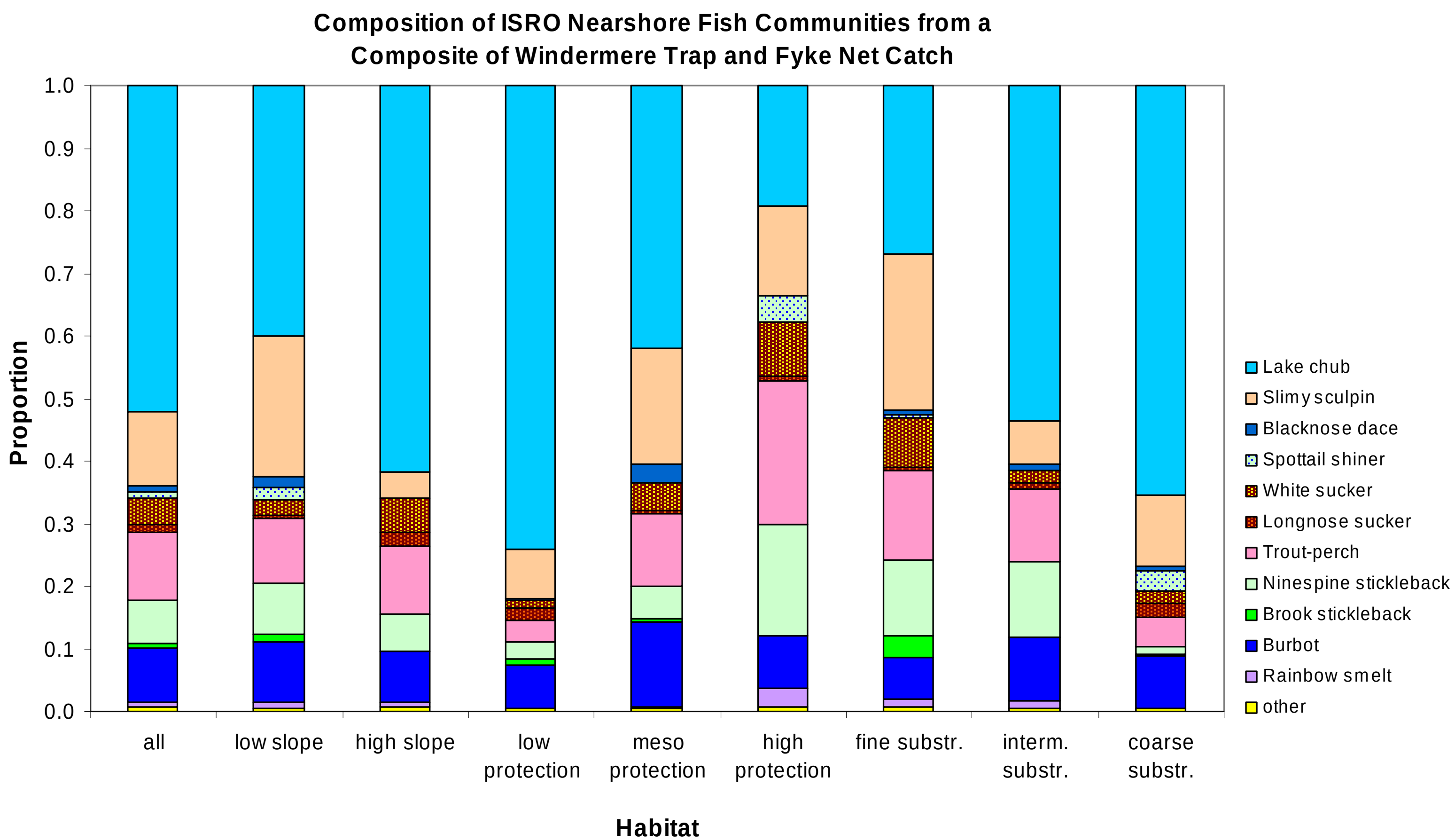


Figure 20. Composition of nearshore fish communities in Isle Royale using *Adjusted Species Abundance* to generate a composite of all samples from Windermere trap and fyke net sets, 2004. Protection levels derived from EEI (embayment exposure index): low < 4.0; intermediate 4.0-7.0; high > 7.0. Range of mean substrate sizes (modified Wentworth scale) were fine 0-3.0 (silt to small gravel); intermediate > 3.0-5.0 (large gravel to small cobble); coarse > 5.0 (large cobble to bedrock). Mean slopes > 4.2° were classified as "high" and those < 4.2° were classified as "low".

DISCUSSION

Nearshore fish communities and habitats

Our samples of the nearshore fish communities of the Apostle Islands and Isle Royale shared a number of dominant species, which included ninespine stickleback, slimy sculpin, lake chub, and burbot. There were some differences, however. Brook stickleback was a minor species in ISRO but was a dominant species in some APIS habitats characterized by high slopes and coarse substrates. Trout-perch was a minor species in APIS but in ISRO was a dominant species in highly protected habitats with fine substrates. White sucker was a minor species in APIS but was a common species in ISRO where it was associated with areas of high protection and fine substrates. Species in our samples unique to the nearshore waters of APIS included threespine stickleback, round whitefish, rock bass, johnny darter, logperch, ruffe, and mottled sculpin. Species in our samples unique to ISRO nearshore waters included three minnow species: emerald shiner, spottail shiner, and bluntnose minnow. Of the four dominant species in common in APIS and ISRO nearshore waters, lake chub represents the key indicator species of the nearshore fish community. This species was abundant in all types of nearshore habitats but absent in samples from offshore waters. Of the four dominant nearshore species, only lake chub is an obligate nearshore species (Scott and Crossman 1973; and Becker 1983). At a regional scale, the similarity in composition of nearshore fish communities of APIS and ISRO suggests that the fish communities of the nearshore waters of Lake Superior are drawn from a common source pool and that differences in habitat characteristics and protection from the open lake act as filters (*sensu* Tonn 1990; Tonn et al. 1990) to determine the local composition and structure of those communities.

While the nearshore fish communities of the Apostle Islands and Isle Royale shared a number of dominant species, the habitat associations of these assemblages were quite different. The most diverse communities in APIS were found in association with areas of high slope and intermediate and coarse substrates, which contrasted the pattern observed in ISRO where the most diverse community structure was found in areas of low slope and fine substrates. Reasons for these differences may be related to differences in hydrographic and geologic characteristics of the two regions. The Apostle Islands consists of an archipelago that extends well out into Lake Superior so that the nearshore waters of the islands are exposed to the open lake. The underlying bedrock is highly erosive sandstone, which creates a range of shorelines ranging from those with low slope and sandy substrates to higher slope with exposed bedrock strewn with boulders, cobble and finer substrates. Nearshore areas with low slope and fine and intermediate substrates were more affected by wave and surf action, resulting in less aquatic vegetation and cover. Areas with higher slope and coarse substrates were deeper, less impacted by wave and surf action, and offered more structure and cover. These structurally complex nearshore habitats in APIS harbored more diverse assemblages of fishes. Isle Royale is a large island situated well out into Lake Superior so that its perimeter shoreline is exposed to the open lake. The underlying bedrock is basalt, which is very resistant to erosion, and results in a rugged shoreline composed largely of exposed bedrock, boulders and large cobble. Isle Royale has many embayments, particularly in the NE end of the island. Nearshore habitat at the mouths of these embayments was characterized by steep slopes and coarse substrates, which creates complex structure and cover, but offers little protection from the open lake. The heads of these embayments were well protected from the open lake and contained habitat of low slope and fine substrates, which were structurally simple. In Isle Royale, the most diverse assemblages were associated with areas of high protection but little structure or cover. These results suggest that for nearshore fish communities in Lake Superior, protection from the effects of the open lake is a prime determinant of fish community structure. This contrasts with studies of stream fish communities and inland lake nearshore communities which have shown that habitat structure is a prime determinant of community structure, e.g., (Gorman and Karr 1978; Gorman 1987, 1988; Benson and Magnuson 1992; Hatzenbeler et al. 2000). However, our interpretation of determinants of structuring of local communities still fit within the conceptual framework proposed by Tonn (1990) and Tonn et al. (1990); starting from a source pool of species, structuring of communities at the local level is determined by a series of processes that act as filters at the continental, regional, lake/watershed, and finally local level.

Historical changes in species composition

Hubbs and Lagler (1949) collated records of nearshore fishes from Isle Royale in Lake Superior during 1904-1945, thus constituting a baseline inventory for future studies (Appendices G, H). During 1945 they sampled fish communities with seines in shallow habitats (< 1 m) including stream mouths and adjacent areas at the protected heads of bays or along embayments (33 locations), along shorelines at 4 locations, and a bog pond close to Lake Superior. Gillnets were used to sample fish in the deeper water habitat (2-15 m) of embayments (8 locations). One site in Siskiwit Bay > 2 m depth was sampled by a trolling spoon. Collection records from the individual sites were not reported, thus descriptions of fish communities by Hubbs and Lagler were generalized. Another issue was that ~70% of their nearshore sample locations were situated in stream mouths within protected coves and heads of embayments. Nonetheless, comparison of results from Hubbs and Lagler (1949) with our recent inventory shows that the nearshore fish communities of Isle Royale have remained largely intact since the early 20th century. Hubbs and Lagler reported 23 species from nearshore habitats compared to our 18 species from fyke nets and Windermere traps in 2004, and 23 from electrofishing surveys in nearshore areas in 2001-2004 (O. Gorman, unpublished data), yielding a 2001-2004 composite of 28 nearshore species (Appendix G). New records in our inventory included coho salmon (*Oncorhynchus kisutch*), blacknose dace (*Rhinichthys atratulus*), bluntnose minnow (*Pimephales notatus*), central mudminnow (*Umbra limi*), and johnny darter (*Etheostoma niger*). With the exception of coho salmon, which was introduced into Lake Superior in the later part of the 20th century, the other species were likely to have been present at the time of Hubbs and Lagler's 1945 field work. We also captured emerald shiner (*Notropis atherinoides*), spotfin shiner (*N. hudsonicus*), and fathead minnow (*P. promelas*) in nearshore habitat whereas Hubbs and Lagler only reported these species from inland lakes and streams. We suspect these omissions by Hubbs and Lager were the result of not sampling a greater diversity of nearshore habitats. Unlike Hubbs and Lagler we did not take encounter sea lamprey (*Petromyzon marinus*), lake sturgeon (*Acipenser fulvescens*), or walleye (*Sander vitreum*), but we suspect these species are present in the marginal waters of Isle Royale. Non-native species reported by Hubbs and Lagler (1949) included rainbow trout (*Oncorhynchus mykiss*) and rainbow smelt, both of which we recorded from our recent surveys.

Early published records of nearshore fishes of the Apostle Islands, as far as we have been able to determine, do not exist, and gray-literature reports from the 1980s were not available for review. Of the 21 species we captured in nearshore habitat in the Apostle Islands, 16 are in common with with Hubbs and Lagler's (1949) survey of Isle Royale nearshore waters. Of the five species not in common, two (blacknose dace and johnny darter) are likely to have been present in marginal waters Isle Royale at the time of Hubb's and Laglers' 1945 survey, one (rock bass, *Ambloplites rupestris*), may not be present there, and two (ruffe, *Gymnocephalus cernuus* and threespine stickleback, *Gasterosteus aculeatus*) are non-native fishes introduced into Lake Superior in the late 20th century.

Hubbs and Lagler's (1949) description of fish communities of the "exposed shoreline" of Isle Royale and protected coves and stream mouths agreed largely with our more quantitative survey. Hubbs and Lagler's "common associates" of exposed shorelines included longnose and common suckers, lake chub, trout-perch, mottled and slimy sculpins, and ninespine stickleback. Common associates of protected coves and stream mouths included the aforementioned species less longnose sucker and mottled sculpin with the addition of brook stickleback (*Culaea inconstans*).

<u>Nearshore and offshore fish communities</u>

The structure of the nearshore fish communities of the Apostle Islands and Isle Royale contrasted strongly with that of the offshore zone, as represented by offshore samples from the Apostle Islands region. The nearshore community was dominated by an assemblage of demersal species, including slimy sculpin, ninespine stickleback, trout-perch and burbot, and the only conspicuous pelagic species was the lake chub. Nearshore specialists well represented in our samples included lake chub, white sucker, johnny darter, logperch, brook stickleback, blacknose dace, and spottail shiner. The assemblage of the demersal species in the offshore fish community showed the greatest affinity to the nearshore community, primarily by the shared species slimy sculpin, ninespine stickleback, trout-perch and burbot. The pelagic assemblage in the offshore community was dominated by coregonids, principally lake whitefish, lake herring and bloater, which were present in nearshore habitat, but as far as we could determine, were not important components of the nearshore pelagic assemblage.

Although nearshore habitats can provide nursery habitat for early life stages of offshore fishes (Wei et al. 2004), early life stages of offshore species were not common in our nearshore samples in APIS and ISRO. Juveniles of species common in offshore samples and present in our nearshore samples included ninespine stickleback, burbot, slimy sculpin, longnose sucker, trout-perch, rainbow smelt and coregonids lake whitefish and lake herring. It is possible that the low relative abundance of coregonids in our nearshore catches may be a reflection of gear or sampling bias; coregonids in nearshore habitats may show strong diel variation in habitat use or may be more abundant in mid-pelagic strata, well above the encounter paths to capture in our bottom-oriented sampling with traps and trawls.

<u>Patterns of Species Distribution Relative to Shoreline Features of the Great Lakes</u>

Based on Wei et al.'s (2004) correlation of fish distributions to features of Great Lakes coastlines, the species of the nearshore waters of APIS and ISRO are composed largely of species from the open-water and intermediate taxocenes (81 and 83%, respectively). Applying thermal preferences of Great Lakes fishes by Wei et al. (2004) and Coker et al. (2001) showed the species of nearshore waters of APIS and ISRO to be composed largely of cool to cold water species (95 and 94%, respectively). Using Wei et al's (2004) generalized shoreline classification, most of the APIS shoreline would fall into the coarse beach, bedrock, bluff and sandy beach classes and most of the ISRO shoreline would fall into the bedrock and coarse beach classes. Only a small fraction would be classified as coastal wetlands; 3 of 18 sites sampled in APIS would be classified as wetlands, and an undetermined small portion of the heads of embayments in ISRO would be classified as wetlands. If all shoreline habitat in APIS and ISRO were classified as either bedrock, bluff, coarse beach or sandy beach, we might expect ~92% of the species to be from the intermediate and open-water taxocenes (Wei et al. 2004). Also based on Wei et al's classification we might expect 87% of the species in these shoreline classes to be from the cool to cold water thermal preference groups. Although these values are in general agreement with our findings for APIS and ISRO, differences may be the result of Wei et al's summarization of patterns across all of the Great Lakes.

Although wetlands were uncommon features of coastal habitat in APIS and ISRO, they may have importance to the Lake Superior fish community that far outweighs their relative areal importance. We found that ≥ 50% of the species present in nearshore waters of APIS and ISRO belonged to the Great Lakes open-water taxocene and 64% of the species in highly protected heads of bays in ISRO were members of the open-water taxocene. As shown by Chubb and Liston (1986), Jude and Pappas (1992), and Wei et al. (2004), coastal wetlands are used disproportionately to their abundance by open-water species with cold and cold-cool water thermal preferences. In addition to wetland habitat, Wei et al. (2004) showed that nearshore waters associated with bedrock, sandy beach-dunes, and bluffs were widely used by the Great Lakes fish community and accounted for 62% of the total shoreline of the Great Lakes. Frequent occurrence of fish in these nearshore habitats indicates use by adults and juvenile stages and migrants and residents for spawning, nursery grounds and temporary shelter and feeding (Edsall and Charlton 1997). Larvae and early life history stages of some cold water species, notably lake herring and lake whitefish, show a preference for wetland habitat and nearshore waters in the Great Lakes (Mitsch and Gosselink 2000; Clady 1976; Liston et al 1986; Jude et al. 1998; Freeberg et al. 1990). In accordance with these findings, our sampling in APIS and ISRO revealed the presence of juvenile lake herring and lake whitefish in nearshore habitats. Wei et al. (2004) noted a strong association of burbot, a cold-water offshore species with wetlands and nearshore waters, which is in agreement with our observation of the relative abundance of burbot in the protected heads of embayments in ISRO. We also note that brook trout, which is considered to be an open-water predator species with a cold water thermal preference (Wei et al. 2004) was most common in the middle and upper portions of embayments in ISRO (Gorman and Moore *in review*). The persistence of brook trout populations in these areas may be dependent on the production of small fish in these pockets of relatively productive habitats nestled in the otherwise harsh environment of northern Lake Superior.

Gear comparisons

Side-by-side comparisons of catches from Windermere traps and 5.2 m bottom trawls in the Apostle Islands yielded very different estimates of the nearshore community composition. We found that fish were not efficiently captured during daylight hours in shallow, clear waters of nearshore areas with bottom trawls. Even in deeper offshore waters, bottom trawls conducted during daylight hours do not yield a fully representative sample of the fish community over the 15-100 m depth interval (Stockwell et al. 2006; Yule et al., *in press*). Reasons for this lack of representation include evasion of the trawl, inefficiency in capture of benthic fishes, and the location of some species above the trawl path, i.e., higher in the water column. Night time bottom trawling addresses visual evasion but not inefficiency or absence of fish in area sampled. Another factor affecting the utility of bottom trawls is applicability to different habitats; bottom trawls can only sample effectively in areas with relatively low slope and even bottoms devoid of large cobbles, boulders and exposed bedrock, whereas Windermere traps can sample the full range of nearshore habitats.

We argue that Windermere traps yielded more representative samples than day bottom trawling. Our reasons include: 1) Ability to sample the full range of habitats in nearshore waters. Traps can be deployed in habitats ranging from low-slope sandy areas to habitats characterized by bedrock, boulders and irregular bathymetry. 2) Twenty-four hour sets sample fish over the entire diel activity cycle. 3) Catches reflect distribution of fishes by local habitat features. When set in arrays, catches can reflect gradients in species distribution and habitat use. 4) Traps are relatively easy to deploy. No specialized or expensive equipment or vessels are required to deploy Windermere traps and can be safely deployed and retrieved over a wider range of weather and sea conditions compared to bottom trawling. Drawbacks include differential bias in capture and escapement rates for different species and the inability to translate capture data into estimates of areal density and biomass. We note that capture biases are reduced by limiting soak times to < 24 hr and setting traps in arrays (Hamley and Howley 1985; Gorman 1994).

At Isle Royale we used both Windermere traps and fyke nets and found differences in the catches when deployed in the same habitats. Catch composition of traps and fyke nets was similar in areas of low protection, high gradient, and coarse substrate. These areas were located near the mouth of embayments, which are relatively unprotected from the lake and subject to strong wind and wave action. Slopes were typically high and cobble, boulder and bedrock dominated the substrate. As habitat became more protected (further inside the embayment) average substrate and slope was smaller, and the similarity of catch composition between traps and fyke nets decreased. And although the composition of fyke nets did not change markedly in more protected habitats, that of Windermere traps did change—and community composition as measured by traps was relatively distinct among areas with fine to coarse substrate, high and low slope, and high to moderate protection. Overall, we found that Windermere trap catches were more responsive in reflecting differences in nearshore habitat characteristics.

We propose that differences in sampling efficiencies of fyke nets and Windermere traps are related to fish behavior and the relative size differences of the gear. The size of gear is likely to affect encounter probability and catch rates. For example, the encounter portion of a fyke net is the 15 m long lead wall, and for the much smaller Windermere trap is the 1.25 m length of the trap. When small traps are set in grids, fish encounter the closest trap within habitat currently being used and are recruited to the traps over relatively short distances, so that catches reflect fish that are present in local habitats. The ability of small traps set in arrays to describe habitat use and segregation has been thoroughly demonstrated in stream and riverine fish communities (Mendelson 1975; Gorman and Stone 1999). Fyke nets rely on herding fish from a travel line parallel to shore along a perpendicular lead wall down the slope to the trap some 15 m from the wetted edge. For example, after encountering the lead wall, and individual fish may have to swim down slope across microhabitats of different substrate composition to a depth > 3 m to be captured in the trap. Thus only relatively vagile species are likely to be captured in fyke nets. In this way, fyke nets select for species that readily move from shallow to deeper water and traverse a range of nearshore microhabitats to be captured. If so, fyke net catches represent species with more generalized habitat associations and thus are not likely to be as responsive to localized habitat characteristics as with Windermere trap catches.

Recommendations for future research

Various investigators have noted the paucity of studies on nearshore communities of the Great Lakes despite the potentially pivotal role nearshore habitats play in the health and productivity of the Great Lakes (Chubb and Liston 1986; Jude and Pappas 1992; Keough et al. 1996, 1999; Wei et al. 2004). Understanding the functional importance of nearshore waters to the Great Lakes fish communities is critical because these habitats are rapidly disappearing or being altered by human activities (Jaworski and Raphael 1978; Chubb and Liston 1986; Chow-Fraser and Albert 1999). To our knowledge, our study is the first of its kind to describe nearshore fish communities and their habitat associations in Lake Superior proper. We evaluated various sampling methods and developed an effective sampling design and habitat assessment methodology (Gorman and Moore *in review*). We defined the community structures and distribution of fishes across a range of nearshore habitats in two regions of Lake Superior (APIS and ISRO) and compared these findings to offshore communities to identify potential linkages. Although we provided some initial descriptions of habitat associations for individual species and their nearshore communities, additional research is required to fully understand these habitat associations. Because many Great Lakes fishes use nearshore habitats for spawning and rearing (Chubb and Liston 1986; Stephenson 1990; Jude and Pappas 1992; Edsall and Charlton 1997; Wei et al. 2004) there is a need to understand the relationship between life history stage for key species and dependency on nearshore habitats. Unfortunately, there have been few detailed studies of food webs and bioenergetics of nearshore fish communities and their linkages to the larger lake community (Keough et al. 1996; Wei et al. 2004). Future studies should address this information gap because productivity in nearshore areas may be critical to productivity of commercially important fish stocks in the open Lake.

Recommendations for long-term monitoring of nearshore fish communities

The choice of sampling gear and sample design for a long-term monitoring program is dependent on the objectives. For example, if monitoring species richness is the primary goal, sampling design is of less importance than using multiple gear types to maximize chances of including all species (Jackson and Harvey 1997). Most modern monitoring programs emphasize measuring a suite of community attributes including species richness, community structure, density and biomass, and habitat associations; e.g., Benson and Magnuson (1992) and Hatzenbeler et al. (2000). In surveys that use multiple gears in complementary fashion over a range of habitats (e.g., small traps in shallow habitat and trap nets in deeper habitat) simple combination of catch data to estimate relative abundances is not appropriate (Jackson and Harvey 1997). Because sampling design is critical to accurate measurement of fish community attributes, use of multiple gear types can potentially present problems of data compatibility, comparability, and accuracy. A single sample gear that can be used over a broad array of habitat types is preferable because direct comparisons of data between years, locations, and habitat types are straightforward. Data from single sampling gear designs are more robust and more accurately depict trends in data series (Jackson and Harvey 1997). However, only the use of multiple gears will ensure that most species present in a habitat are captured, but the key is to find gears that can sample the same range of nearshore habitats. Hatzenbeler et al. (2000) and

Drake and Pereira (2002) used both passive and active sampling gears in nearshore waters of inland lakes to describe fish communities. Because these gear types were used to sample the same habitats, they argued that catch data could be combined additively. We argue that data from different gears sampling the same habitat should not be simply added or averaged but combined using our *Adjusted Species Abundance*. The timing of sampling nearshore fish communities does not appear to be particularly critical; Hatzenbeler et al. (2000) found that sampling anytime during warm months (late spring to early fall) produced similar measures of community attributes. What is critical, however, is standardization of sample design and methodology to overcome gear-induced variation (Lester et al. 1996).

Our experience in using bottom trawls, fyke nets, and Windermere traps in the Apostle Islands and Isle Royale to assess nearshore fish communities allows us to recommend appropriate sampling methods for long-term monitoring. Fish traps and fyke nets provide better estimates of population size structure and relative abundance than gillnets (Guy et al. 1996) or electrofishing (Schultz and Haines 2005) but the design and mesh size can affect catch composition (Shoup et al. 2003). We note, however, that gillnets are more effective than small traps in capturing pelagic species such as lake herring and lake whitefish. Ryan (1984) successfully used fyke nets to track seasonal changes in size composition and abundance of brook trout and Atlantic salmon in Newfoundland lakes. As suggested previously, Windermere traps are preferred over trawling for their ability to sample across the full range of nearshore habitats and for their ease of deployment and retrieval. We have also shown that Windermere traps are relatively sensitive to detecting changes in community structure relative to varying habitat characteristics. Small traps should be set in arrays to minimize the distance fish must travel before capture and thus assure a strong association of capture with localized habitat conditions (Mendelson 1975; Gorman 1994; Gorman and Stone 1999; Stone and Gorman 2006). To address the under-representation of some pelagic species, we suggest suspending traps in the water column at various depths within the arrays. To elucidate diel activity patterns in nearshore fishes, traps should be lifted and reset at 6-12 hr intervals. As we have done in this study, we recommend that sampling locations be distributed in a stratified-random fashion to ensure unbiased coverage of nearshore habitats. If rare habitats have been identified, these areas can be included as supplementary samples.

Our results indicate that fyke nets are not as sensitive as Windermere traps (deployed in arrays) at detecting fish-habitat associations. Moreover, fyke nets are limited to a fixed set geometry determined by a 15 m lead wall that must be tied to shore and as a result can only be set in a limited number of shoreline habitats. However, fyke nets appear to be efficient in capture of larger fish, e.g., suckers and brook trout (Ryan 1984; O. Gorman, *personal observation*). Nearshore electrofishing should be considered as a corollary to trapping because of the ability to sample over a large area in a short period of time. However, demersal and benthic fishes are underrepresented in electrofishing samples (Reynolds 1996; O. Gorman, *personal observation*). Because of this bias we recommend using a presence/absence or applying a relative abundance classification (absent, rare, common, abundant) for estimating fish abundance indices from electrofishing survey data.

Our research on the offshore fish community has provided us with experience in ship-based sampling methods such as mid-water trawls and hydroacoustic detection. We have determined that night-time sampling with a combination of mid-water and bottom trawls provides a relatively accurate sample of offshore fish communities (Stockwell et al. 2006; Yule et al., *in press*). In the depth interval between 15 and 30 m, there is a gap in our knowledge of how fish use this habitat zone due to a lack of sampling. We suggest conducting night-time bottom trawling and hydroacoustics in the shallow waters of the nearshore and just offshore zones to gain increased understanding as to how this habitat is used by the fish community of Lake Superior.

Based on our experience describing fish community structures in nearshore waters of APIS and ISRO, we recommend the following guidelines for developing a long-term monitoring program of nearshore fish communities:

1. Establish fixed sampling locations in a stratified-random design so that major near-shore habitats are represented.
    a. Major nearshore habitat types in APIS include: low slope with fine substrates, low slope with coarse substrates, high slope with coarse substrates, high slope with bedrock substrate, and wetland/estuary. A minimum of 6 sample sites for each habitat type should be established, with sites evenly divided between outer and inner shorelines of islands.
    b. Major nearshore habitat types in ISRO include: low slope with fine substrates, low slope with coarse substrates, high slope with coarse substrates, high slope with bedrock substrate, and low, intermediate, and high protection. Sampling should be conducted in major embayments (Siskiwit Bay, Rock Harbor, Tobin Harbor, Duncan Harbor, Five Finger Bay, Robinson Bay, McCargo Harbor, Todd Harbor, Washington Harbor). Sample sites should be stratified by protection level and then by available habitat within protection level (minimum of two sites per protection level per embayment).

2. Conduct sampling during summer months (mid-June through mid-September), preferably on an annual or bi-annual basis. Avoid splitting samples for a region (APIS, ISRO) among years as inter-year variation cannot be controlled.

3. Primary sampling devices: Windermere traps and fyke nets. When possible, boat electrofishing surveys should be incorporated into the sampling scheme.

This sampling design will allow estimation of species richness, community structure, relative abundance and habitat associations.

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Appendix A. Nearshore sampling stations in the Apostle Islands, Lake Superior. USGS station refers to closest offshore sites where annual spring bottom trawl sampling has been conducted since 1976. Sample gear: T = 5.2-m bottom trawl, W = Windermere trap. Mean slope is the grand mean of slopes in degrees as measured over a 4 x 20 m sampling grid at each station. Gradient: low gradient = mean slope < 4.2°, high gradient = mean slope ≥ 4.2°. Latitude and longitude are shown in decimal degrees.

Station	Island	Location	USGS station	Gear	Principal Substrate	Mean Slope	Gradient	Latitude	Longitude
1	Sand	west side Sand Island	139		sand	1.99	low	46°58.277'N	090°58.724'W
2	Sand	northwest side Sand Island			rock	7.44	high	47°00.210'N	090°56.255'W
3	Raspberry	northeast side Raspberry Bay	71	T	rock	3.42	low	46°58.688'N	090°47.031'W
4	Bear	southeast side Bear Island	75	T,W	sand	6.16	high	47°00.215'N	090°44.838'W
5	Devils	east side Devils Island			rock	5.73	high	47°04.085'N	090°43.834'W
6	Otter	northeast side Otter Island			gravel, cobble	6.31	high	47°00.129'N	090°40.279'W
7	Little Manitou	west side Little Manitou Island			gravel, rock, sand	7.26	high	46°57.713'N	090°41.168'W
8	Cat	west side Cat Island			sand	4.11	low	47°01.196'N	090°34.186'W
9	Cat	south side Cat Island	45	W	sand	4.18	low	46°59.806'N	090°33.795'W
10	Outer	west side Outer Island	44	W	sand	3.15	low	47°01.420'N	090°28.838'W
11	Outer	northeast side Outer Island		W	rock	7.29	high	47°04.631'N	090°23.822'W
12	Outer	east side Outer Island		W	rock	4.78	high	47°04.456'N	090°23.667'W
13	Outer	south side Outer Island	52	W	sand	2.90	low	46°59.758'N	090°27.359'W
14	Michigan	north side Michigan Island		W	sand	4.45	high	46°53.807'N	090°27.585'W
15	Michigan	northeast side Michigan Island			rock	2.31	low	46°53.997'N	090°26.932'W
16	Michigan	southeast side Michigan Island	24	T,W	sand	3.51	low	46°52.191'N	090°29.862'W
17	Madeline	northeast side Madeline Island		T,W	rock	3.37	low	46°51.160'N	090°34.671'W
18	Madeline	northwest side Madeline Island			sand	4.60	high	46°52.480'N	090°36.959'W
19	Stockton	Presque Isle Bay, Stockton Island	2	T,W	sand	2.05	low	46°55.233'N	090°33.345'W
20	Stockton	west side Stockton Island	87	T,W	sand	3.29	low	46°55.761'N	090°38.889'W
21	Oak	east side Oak Island			rock	4.24	high	46°55.239'N	090°41.323'W
22	Hermit	west side Hermit Island		T,W	gravel	4.65	high	46°53.442'N	090°41.800'W
23	Madeline	northwest side Madeline Island		T,W	rock	3.67	low	46°51.593'N	090°38.267'W
24	Basswood	east side Basswood Island	86	W	gravel	12.57	high	46°50.115'N	090°44.879'W
25	Stockton	southeast side Stockton Island		T,W	sand	2.24	low	46°55.595'N	090°32.792'W
26	Sand	east side Sand Island		T	sand	1.94	low	46°58.763'N	090°56.054'W
27	Stockton	north side Stockton Island		T,W	sand	5.33	high	46°57.404'N	090°35.105'W

Appendix B. Catch summary for APIS by gear type, 2003-2004. Raw catch data (number of fish caught) is tabulated by gear type, station, and species code. Species codes are defined in Table 1.

Windermere Trap

	Species Code															
Stat.	BRB	BKS	TSS	NSS	TRP	LNS	WHS	LKC	BND	RKB	JND	LGP	MTS	SLS	SPS	Total
4	4								1					11		16
9								2						3		5
10	4						1								1	6
11						1	1	4								6
12	1							20								21
13	24						1	4						2		31
14	3			78				8								89
16	1			5										10	1	17
17	1			2				26						1		30
19				2										4		6
20	5				1									3		9
22	6				4				1					8		19
23	3									1				11		15
24	13	68	7		1			3		1	1		4	19		117
25	1			4				1	1					7		14
27	3				3							2		9		17
Total	69	68	7	91	9	1	3	68	3	2	1	2	4	88	2	418

5.2-m Bottom Trawl

	Species Code															
Stat.	RNS	BRB	TSS	NSS	TRP	LKH	LWF	RWF	WHS	LND	JND	LGP	RFF	SLS	SPS	Total
3		6	1	1										3		11
4		1							1				1	10		13
16				6				1			13	1		10		31
17	2			75	5						8			3	3	96
19	13			124							2	11		1		151
20				1							5			8		14
22	1			26										2	3	32
23				3	2						1	1		6	1	14
25	15			381							6	6		6	2	416
26						1	1	3	1	1	15			1		23
27	1			527	9		1	2			2	6		10		558
Total	32	7	1	1144	16	1	2	6	2	1	52	25	1	60	9	1359

Appendix C. Nearshore sampling stations at Isle Royale, Lake Superior. Sample gear: W = Windermere trap, F= fyke net. Mean Substrate is the mean primary substrate size according to a modified Wentworth scale. Principal Substrate and Substrate Size provide descriptive categories for Mean Substrate: fine: < 3, intermediate: 4 - 5, coarse: > 5. Mean Slope is the grand mean of slopes in degrees as measured over a 4 x 20 m sampling grid at each station. Gradient: low gradient is defined as mean slope < 4.2° and high gradient is defined as mean slope ≥ 4.2°. EEI is the embayment exposure index (ratio of distance from mouth over width at mouth of bay) and Protection provides a descriptive category for EEI: low: < 4; meso: 4 - 7; high: > 7. Latitude and Longitude are shown in decimal degrees.

Location	Station	Gear	Mean Substr.	Principal Substrate	Substrate Size	Mean Slope	Gradient	EEI	Protection	Latitude	Longitude
Five Finger Cove	FB23	W	6.6	boulder,bedrock	Coarse	7.5	High	-0.91	Low	48°09.774'N	88°31.007'W
	FB24	F	6.2	boulder,bedrock	Coarse	11.84	High	0.01	Low	48°09.660'N	88°31.270'W
	FB27	F	6.4	boulder,bedrock	Coarse	6.63	High	-0.40	Low	48°09.584'N	88°30.774'W
	FB29	F	2.7	sand	Fine	9.92	High	0.12	Low	48°09.464'N	88°31.120'W
	FB30	F	6.1	boulder,bedrock	Coarse	7.29	High	0.45	Low	48°09.420'N	88°31.443'W
	FB39	W	6.2	boulder,bedrock	Coarse	2.96	Low	0.25	Low	48°09.829'N	88°31.595'W
Lane Cove	LC47	F	5.6	boulder,bedrock	Coarse	2.08	Low	0.01	Low	48°08.865'N	88°34.121'W
Pickerel Cove	PC40	F	2.7	sand	Fine	10.42	High	0.01	Low	48°09.033'N	88°33.451'W
	PC48	F	2.9	sand	Fine	7.76	High	2.34	Low	48°08.785'N	88°34.639'W
	PC49	F	3.3	gravel,cobble,sand	Intermediate	1.94	Low	2.90	Low	48°08.531'N	88°35.321'W
	PC50	F,W	2	sand	Fine	0.6	Low	3.30	Low	48°08.437'N	88°35.916'W
	PC51	F,W	3.7	gravel,cobble,sand	Intermediate	6.28	High	3.90	Low	48°08.189'N	88°36.565'W
	PC52	F	1.6	sand	Fine	1.36	Low	4.39	Meso	48°08.067'N	88°37.266'W
	PC53	F	3.9	gravel,cobble,sand	Intermediate	7.94	High	4.70	Meso	48°07.883'N	88°37.592'W
	PC54	F	3.2	gravel,cobble,sand	Intermediate	1.67	Low	5.09	Meso	48°07.703'N	88°38.108'W
	PC55	F,W	6	boulder,bedrock	Coarse	5.03	High	5.66	Meso	48°07.426'N	88°38.760'W
	PC56	F	4.4	gravel,cobble,sand	Intermediate	4.93	High	6.20	Meso	48°07.231'N	88°39.484'W
	PC57	F	5.6	boulder,bedrock	Coarse	7.75	High	5.90	Meso	48°07.413'N	88°39.208'W
	PC58	F	6.1	boulder,bedrock	Coarse	7.13	High	5.35	Meso	48°07.626'N	88°38.561'W
	PC59	F	5	gravel,cobble,sand	Intermediate	8.39	High	4.74	Meso	48°07.923'N	88°37.830'W
	PC60	W	6	boulder,bedrock	Coarse	3.69	Low	4.13	Meso	48°08.252'N	88°37.073'W

Appendix C, continued.

Location	Station	Gear	Mean Substr.	Principal Substrate	Substrate Size	Mean Slope	Gradient	EEI	Protection	Latitude	Longitude
Robinson Bay	RB61	F	4.6	gravel,cobble,sand	Intermediate	7.16	High	5.02	Meso	48°08.051'N	88°37.748'W
	RB62	F	3.9	gravel,cobble,sand	Intermediate	2.43	Low	5.55	Meso	48°07.824'N	88°38.477'W
	RB63	F	3.3	gravel,cobble,sand	Intermediate	6	High	6.05	Meso	48°07.767'N	88°39.130'W
	RB64	F	3.1	gravel,cobble,sand	Intermediate	6.94	High	5.12	Meso	48°08.055'N	88°38.574'W
	RB66	W	1.6	sand	Fine	3.43	Low	4.07	Meso	48°08.594'N	88°37.352'W
	RB67	F	5.8	boulder,bedrock	Coarse	6.56	High	3.79	Low	48°08.651'N	88°37.002'W
	RB68	F	6	boulder,bedrock	Coarse	6.75	High	3.18	Low	48°08.845'N	88°36.292'W
	RB69	F	6.5	boulder,bedrock	Coarse	7.95	High	3.29	Low	48°08.763'N	88°36.328'W
	RB70	F	3.8	gravel,cobble,sand	Intermediate	6.92	High	4.03	Meso	48°08.514'N	88°37.004'W
	RB71	F	4.7	gravel,cobble,sand	Intermediate	7.94	High	3.46	Low	48°08.726'N	88°36.521'W
	RB74	W	5.7	boulder,bedrock	Coarse	4.01	Low	4.24	Meso	48°08.351'N	88°36.818'W
	RB75	W	4.6	gravel,cobble,sand	Intermediate	4.16	Low	2.64	Low	48°09.057'N	88°35.629'W
	RB76	W	6.1	boulder,bedrock	Coarse	6.91	High	2.26	Low	48°09.136'N	88°35.099'W
Tobin Harbor	MP1	F	2.9	sand	Fine	19.7	High	0.47	Low	48°09.770'N	88°27.358'W
	MP2	F	3.3	gravel,cobble,sand	Intermediate	10.68	High	1.04	Low	48°09.640'N	88°27.610'W
	MP3	W	2.1	sand	Fine	14.12	High	1.60	Low	48°09.498'N	88°27.846'W
	MP4	W	3.3	gravel,cobble,sand	Intermediate	12.2	High	2.07	Low	48°09.398'N	88°28.083'W
	MP7	W	2.5	sand	Fine	8.32	High	2.94	Low	48°09.249'N	88°28.497'W
	MP18	W	1.7	sand	Fine	3.06	Low	8.45	High	48°08.012'N	88°31.171'W
	MP19	F	2.1	sand	Fine	3.32	Low	8.87	High	48°07.943'N	88°31.418'W
	MP20	F	4.2	gravel,cobble,sand	Intermediate	10.13	High	9.35	High	48°07.872'N	88°31.670'W
	MP21	F	1.9	sand	Fine	4.49	High	9.94	High	48°07.759'N	88°31.975'W
	MP22	F	0.9	sand	Fine	1.53	Low	10.23	High	48°07.698'N	88°32.192'W
	MP23	F	4.5	gravel,cobble,sand	Intermediate	10.71	High	9.72	High	48°07.829'N	88°32.908'W
	MP29	W	4	gravel,cobble,sand	Intermediate	12.76	High	6.56	Meso	48°08.555'N	88°30.422'W

Appendix C, continued.

Location	Station	Gear	Mean Substr.	Principal Substrate	Substrate Size	Mean Slope	Gradient	EEI	Protection	Latitude	Longitude
Rock Harbor	RH156	W	3.1	gravel,cobble,sand	Intermediate	3.05	Low	18.64	High	48°04.289'N	88°37.266'W
	RH157	F	3.6	gravel,cobble,sand	Intermediate	3.4	Low	19.58	High	48°03.808'N	88°37.491'W
	RH158	F	2	sand	Fine	1.21	Low	20.55	High	48°03.677'N	88°38.230'W
	RH159	F	4.8	gravel,cobble,sand	Intermediate	1.85	Low	21.12	High	48°03.749'N	88°38.704'W
	RH160	F	2.6	sand	Fine	1.34	Low	20.45	High	48°04.042'N	88°38.540'W
	RH161	F,W	2	sand	Fine	1.88	Low	19.45	High	48°04.410'N	88°38.034'W
	RH165	F	6.2	boulder,bedrock	Coarse	4.85	High	14.95	High	48°05.617'N	88°35.496'W
	RH167	F	4.4	gravel,cobble,sand	Intermediate	8.18	High	12.64	High	48°06.133'N	88°34.143'W
	RH168	F	2.5	sand	Fine	6.31	High	11.49	High	48°06.418'N	88°33.476'W
	RH169	W	4.6	gravel,cobble,sand	Intermediate	5.82	High	10.34	High	48°06.742'N	88°38.809'W
	RH170	W	4.1	gravel,cobble,sand	Intermediate	11.73	High	9.45	High	48°07.079'N	88°32.402'W
	RH171	F,W	6.2	boulder,bedrock	Coarse	2.16	Low	8.29	High	48°07.454'N	88°31.759'W
	RH172	F	6.9	boulder,bedrock	Coarse	8.34	High	7.22	High	48°07.762'N	88°31.179'W
	RH173	F,W	5.2	boulder,bedrock	Coarse	10.46	High	6.14	Meso	48°08.044'N	88°30.511'W
	RH174	F	6.1	boulder,bedrock	Coarse	11.83	High	4.99	Meso	48°08.409'N	88°29.93'W
	RH175	F	6.2	boulder,bedrock	Coarse	4.88	High	3.93	Low	48°08.685'N	88°29.291'W
	RH176	F	7.1	boulder,bedrock	Coarse	4.45	High	3.17	Low	48°08.734'N	88°28.917'W
	RH177	W	6.1	boulder,bedrock	Coarse	4.34	High	2.22	Low	48°09.110'N	88°28.345'W
Siskiwit Bay	IR96	W	5.2	boulder,bedrock	Coarse	2.43	Low	5.29	Meso	47°54.000'N	88°59.000'W
	IR97	F	2	sand	Fine	0.92	Low	5.57	Meso	47°53.000'N	88°60.000'W
	IR98	F	2	sand	Fine	1.22	Low	5.63	Meso	47°54.000'N	89°00.000'W
	IR99	F	6.3	boulder,bedrock	Coarse	2.35	Low	5.41	Meso	47°54.000'N	88°60.000'W
	IR100	F	3.1	gravel,cobble,sand	Intermediate	2.01	Low	5.46	Meso	47°54.000'N	89°00.000'W
	IR101	F	6.5	boulder,bedrock	Coarse	3.23	Low	5.17	Meso	47°55.000'N	88°60.000'W
	IR102	W	6.1	boulder,bedrock	Coarse	3.21	Low	4.92	Meso	47°55.000'N	88°59.000'W
	IR107	F	6.2	boulder,bedrock	Coarse	1.18	Low	3.53	Low	47°56.000'N	88°55.000'W
	IR112	W	5.8	boulder,bedrock	Coarse	2.61	Low	3.44	Low	47°56.605'N	88°55.438'W
	IR114	F	6	boulder,bedrock	Coarse	2.48	Low	2.88	Low	47°57.159'N	88°54.056'W
	IR115	F	5.2	boulder,bedrock	Coarse	1.61	Low	2.67	Low	47°52.091'N	88°53.379'W
	IR116	F	5.6	boulder,bedrock	Coarse	1.8	Low	2.49	Low	47°57.252'N	88°52.911'W
	IR118	W	6.1	boulder,bedrock	Coarse	2.46	Low	1.92	Low	47°57.825'N	88°51.548'W

Appendix D. Summary of sampling effort (number of sites/stations and area sampled) in ISRO by gear, location (embayment), and habitat characteristics. Fyke nets and Windermere traps were set for 24 hours at each site in summer, 2004. Windermere traps were set in arrays of 12 traps at sites listed.

Fyke Nets- number of sites

		Protection			Gradient		Substrate		
Location	**all**	**low**	**meso**	**high**	**low**	**high**	**fine**	**interm**	**coarse**
Five Finger Bay	4	4				4		1	3
Lane Cove	1	1			1				1
Pickerel Cove	13	5	8		4	9	2	7	4
Robinson Bay	9	4	5		1	8		6	3
Tobin Harbor	8	3		5	2	6	4	4	
Rock Harbor	14	2	2	10	6	8	2	4	8
Siskiwit Bay	9	4	5		9		2	1	6
Total	58	23	20	15	23	35	10	23	25

Windermere Traps- number of sites

		Protection			Gradient		Substrate		
Location	**all**	**low**	**meso**	**high**	**low**	**high**	**fine**	**interm**	**coarse**
Five Finger Bay	2	2			2				2
Lane Cove									
Pickerel Cove	4	3	1		2	2	1	1	2
Robinson Bay	4	2	2		3	1	1	1	2
Tobin Harbor	4	2	1	1	1	3	1	3	
Rock Harbor	7	1	1	5	3	4	1	3	3
Siskiwit Bay	4	2	2		4				4
Total	25	12	7	6	15	10	4	8	13

Appendix E. Windermere trap catch summary for ISRO, 2004. Raw catch data (number of fish caught) is tabulated by location (embayment), station, and species code. Species codes are defined in Table 5.

Windermere Trap																				
		Species code																		
Location	**Station**	RNS	BRB	BKS	NSS	TRP	LKH	LWF	BRT	LNS	WHS	EMS	STS	BNM	LND	LKC	BND	SLS	SPS	Total
Five Finger Bay	FB23		1													21		1		23
	FB39		1													10				11
Pickerel Cove	PC50		1	6		1					1					6		3		18
	PC51		2		1	1										2		4		10
	PC55		1	1		20					1					9		3		35
	PC60		2		1	1					1					6		21		32
Robinson Bay	RB66		7							1						2		10		20
	RB74		1								1					7		3		12
	RB75		5			1					1					15		3		25
	RB76		7			3				6						189				205
Rock Harbor	RH156		1		11	1										2		2		17
	RH161		2		15											2		11		30
	RH169		8		2											1		5		16
	RH170		9		14					1						45		2		71
	RH171		1															1		2
	RH173		5													5		1		11
	RH177		4							4						31				39
Siskiwit Bay	IR102		6		1													9		16
	IR112		4			3										6		9		22
	IR118		9		1											5				15
	IR96		4		4													15		23
Tobin Harbor	MP18		1		5											1		17		24
	MP29		7		7		1				1					12		2		30
	MP4		5		6					2	2					96	1	4		116
	MP7		3		8													5		16
Total			97	7	76	31	1			14	8					473	1	131		839

Appendix F. Fyke net catch summary for ISRO, 2004. Raw catch data (number of fish caught) is tabulated by location (embayment), station, and species code. Species codes are defined in Table 5.

Fyke Nets

		Species code																		
Location	**Station**	RNS	BRB	BKS	NSS	TRP	LKH	LWF	BRT	LNS	WHS	EMS	STS	BNM	LND	LKC	BND	SLS	SPS	Total
Five Finger Bay	FB24															3				3
	FB27															1				1
	FB29					1									3	38				42
	FB30										1					7				8
Lane Cove	LC47															30				30
Pickerel Cove	PC40		1																	1
	PC48					21				7	2					337		1		368
	PC49															1				1
	PC50					1	1			5	4		1			208		1		221
	PC51															1				1
	PC52															1				1
	PC53															1				1
	PC54					69					1					45				115
	PC55															1				1
	PC56		1			6					2					11				20
	PC57									1	2					1				4
	PC58															1				1
	PC59			1		3					1									5
Robinson Bay	RB61										6					5				11
	RB62	2	1								4					78		1		86
	RB63		1								2									3
	RB64					1		1								4		1	1	8
	RB67																	1		1
	RB68					25				4						203		1		233
	RB69		2													5				7
	RB70										5					1				6
	RB71		2			3				3						65				73
Rock Harbor	RH157	1				11												1		13
	RH158	4			10	43					1		4							62
	RH159					8					1		28							37

Appendix F, continued.

Fyke Nets

Location	Station	RNS	BRB	BKS	NSS	TRP	LKH	LWF	BRT	LNS	WHS	EMS	STS	BNM	LND	LKC	BND	SLS	SPS	Total
		Species code																		
Rock Harbor	RH160	4	1		28	24					1					8				66
	RH161				1															1
	RH165									2						5				7
	RH167				2	1				1						21		2		27
	RH168		4		6											19				29
	RH171									1								1		2
	RH172									2						16				18
	RH173		1			1										6		1		9
	RH174				2	1				3	1					69				76
	RH175															6				6
	RH176		1		1					3	1					7				13
Siskiwit Bay	IR100					1					2	1		1		25	14			44
	IR101					1					1									2
	IR107															97	1			98
	IR114							1								1				2
	IR115									1	1					93				95
	IR116				1	3		3	1	1	9					2	5			25
	IR97										3					8				11
	IR98															16	8			24
	IR99										1					26				27
Tobin Harbor	MP1															1				1
	MP19										1									1
	MP2				1											5				6
	MP20	7			1													2		10
	MP21	5			1	83		4	1		53					15		9		171
	MP22	2				4		1			10									17
	MP23				2	6										1				9
	MP3				2											2		1		5
Total		25	15	1	58	317	1	10	2	34	116	1	33	1	3	1497	28	23	1	2166

Appendix G. Historical record of fishes of nearshore habitats of Isle Royale. Records from Hubbs and Lagler (1949) represent a composite of records spanning 1904-1945. Records from margins and low lakes < 8 m above Lake Superior are from Table IV, Hubbs and Lagler (1949). Records from the 1-15 m depth nearshore zone are listed on page 93 of Hubbs and Lagler (1949). Common species for the 0-1 m exposed nearshore zone and coves and stream mouths are from page 94 of Hubbs and Lagler (1949); this zone was sampled with seines. ISRO 2004 and APIS 2003-2004 data are from this report. ISRO 2001-2003 "EF" data are from electrofishing surveys conducted around the margins of Isle Royale (O. Gorman, unpubl. data). Asterisks denote introduced species; question marks indicate an unverified record.

		Hubbs & Lagler (1949)				ISRO 2004	ISRO 2001-2003	ISRO 2001-2004	APIS 2003-2004
Common Name	Scientific Name	Margins, low lakes	1-15 m nearshore zone	0-1 m exposed nearshore zone	Coves, stream mouths	traps, nearshore waters	EF, nearshore waters	composite, nearshore waters	traps, trawls
sea lamprey*	*Petromyzon marinus*	x	x						
lake sturgeon	*Acipenser fulvescens*	x	x						
coho salmon*	*Oncorhynchus kisutch*						x	x	
rainbow trout*	*Oncorhynchus mykiss*	x	x				x	x	
brook trout	*Salvelinus fontinalis*	x	x			x	x	x	
lake trout	*Salvelinus namaycush*	x	x				x	x	
siscowet lake trout	*Salvelinus namaycush siscowet*	x	?						
lake herring	*Coregonus artedi*	x	x			x	x	x	x
shortjaw cisco	*Coregonus zenithicus*	x	?						
lake whitefish	*Coregonus clupeaformis*	x	x			x	x	x	x
round whitefish	*Propsopium cylindraceum*	x	x				x	x	x
rainbow smelt*	*Osmerus mordax*	x	x			x	x	x	x
white sucker	*Catostomus catostomus*	x	x	x		x	x	x	x
longnose sucker	*Catostomus commersoni*	x	x	x	x	x	x	x	x
creek chub	*Semotilus atromaculatus*								
pearl dace	*Margariscus margarita*								
lake chub	*Couesius plumbeus*	x	x	x	x	x	x	x	x

Appendix G, continued. Historical record of fishes of nearshore habitats of Isle Royale.

		Hubbs & Lagler (1949)				ISRO 2004	ISRO 2001-2003	ISRO 2001-2004	APIS 2003-2004
Common Name	Scientific Name	Margins, low lakes	1-15 m nearshore zone	0-1 m exposed nearshore zone	Coves, stream mouths	traps, nearshore waters	EF, nearshore waters	composite, nearshore waters	traps, trawls
longnose dace	*Rhinichthys cataractae*	x	x	x	x	x	x	x	x
blacknose dace	*Rhinichthys atratulus*					x	x	x	x
northern redbelly dace	*Phoxinus eos*	x							
finescale dace	*Phoxinus neogaeus*	x							
golden shiner	*Notemigonus chrysoleucas*	x							
emerald shiner	*Notropis atherinoides*	x				x		x	
spottail shiner	*Notropis hudsonicus*	x				x	x	x	
blackchin shiner	*Notropis heterodon*	x							
mimic shiner	*Notropis volucellus*	x							
blacknose shiner	*Notropis heterolepis*								
fathead minnow	*Pimephales promelas*	x					x	x	
bluntnose minnow	*Pimephales notatus*					x		x	
central mudminnow	*Umbra limi*						x	x	
northern pike	*Esox lucius*	x	x				x	x	
muskellunge	*Esox masquinongy*	x	?						
burbot	*Lota lota*	x	x			x		x	x
trout-perch	*Percopsis omiscomaycus*	x	x	x	x	x		x	x
yellow perch	*Perca flavescens*	x	x				x	x	
walleye	*Sander vitreum*	x	x						
logperch	*Percina caprodes*	x							x
Iowa darter	*Etheostoma exile*								
johnny darter	*Etheostoma niger*						x	x	x
pumpkinseed	*Lepomis gibbosus*	x							

Appendix G, continued. Historical record of fishes of nearshore habitats of Isle Royale.

		Hubbs & Lagler (1949)				ISRO 2004	ISRO 2001-2003	ISRO 2001-2004	APIS 2003-2004
Common Name	Scientific Name	Margins, low lakes	1-15 m nearshore zone	0-1 m exposed nearshore zone	Coves, stream mouths	traps, nearshore waters	EF, nearshore waters	composite, nearshore waters	traps, trawls
rock bass	*Ambloplites rupestris*								x
ruffe	*Gymnocephalus cernuus*								x
deepwater sculpin	*Myoxocephalus thompsonii*	x	?						
spoonhead sculpin	*Cottus ricei*	x	x			x	x	x	x
mottled sculpin	*Cottus bairdi*	x	x	x			x	x	x
slimy sculpin	*Cottus cognatus*	x	x	x	x	x	x	x	x
threespine stickleback	*Gasterosteus aculeatus*								x
brook stickleback	*Culaea inconstans*	x	x		x	x		x	x
ninespine stickleback	*Pungitius pungitius*	x	x	x	x	x	x	x	x
Total		**37**	**23**	**8**	**7**	**18**	**23**	**28**	**21**

Appendix H. Isle Royale nearshore locations sampled by Hubbs and Lagler (1949) in 1945. Narrative descriptions are from pages 76-81 of Hubbs and Lagler (1949). Clarifications of location information and units of measure were added. Site 852 is shown on Figure 1 in Hubbs and Lagler, but was omitted from narrative descriptions of sampling locations. Omissions reflect those in Hubbs and Lagler (1949). Sites not listed (813, 817-819, 831, 836-839) are located on inland lakes or > 1 km upstream of stream mouths.

Site No.	Location	Sampling method	Date, 1945	Depth (m)	Habitat Description
797	Lane Cove off of Robinson Bay	gillnet	Jul 15-16	15	center of cove channel
798	Lane Cove, west end	seine	Jul 17	0.6	shoreline and stream mouth
799	Pickerel Cove, side cove	seine	Jul 17	0.6	shoreline, silty bottom, aquatic plants
800	Pickerel Cove, outlet of Lake Eva	seine	Jul 17	0.8	stream mouth and channel, rock, silt, detritus, some aquatic plants
801	McCargoe Cove, mouth (conjoined with Brady Cove)	gillnet	Jul 17-18	2-15	center channel of cove
802	McCargoe Cove, head, outlet from Chickenbone Lake	seine	Jul 18	1.0	stream mouth and channel, rock, gravel, silt, detritus, some aquatic plants
803	McCargoe Cove, outlet from Sargent Lake	seine	Jul 18	0.5	stream mouth and channel, rock, silt, detritus, dense shade
804	McCargoe Cove, stream entering head of Brady Cove	seine	Jul 18	0.5	stream mouth and channel, silt, detritus, some sedges
805	McCargoe Cove, shore of Birch Island	seine	Jul 18	1	shoreline, sand, gravel, rock.
806	Todd Harbor, outlet from Beaver Lake	seine	Jul 19	0.25	stream mouth and channel, sand, silt, detritus
807	Todd Harbor, outlet from Hatchet Lake	seine	Jul 19	1	stream mouth and channel, bedrock, silt, detritus
808	Todd Harbor, outlet from Harvey Lake	seine	Jul 19	1	stream mouth and channel, gravel, sand, silt, detritus
809	Todd Harbor, Pickett Bay, west end	seine	Jul 19	0.8	shoreline and stream mouth, sand, silt, detritus
810	Todd Cove, outlet from Lake Desor	seine	Jul 20	1	stream mouth and channel, gravel, sand, silt, detritus
811	Todd Harbor, shore of Taylor Island	seine	Jul 20	1.2	shoreline, gravel, rock, algae
812	Todd Harbor, between Taylor Island and Florence Pt.	gillnet	Jul 20-21	2-8	center of cove channel
814	Washington Harbor, cove opposite Thompson Island	seine	Jul 22	1	shoreline, stream mouth and channel, rock, sand, silt, detritus
815	Washington Harbor, head, ~300m W of Washington Creek	seine	Jul 22	0.8	shoreline and stream mouth, gravel, sand, silt, detritus
816	Washington Harbor, Windigo Harbor shoal NE of Beaver Is.	gillnet	Jul 24	2	shoal near center of basin, dense aquatic vegetation
820	Washington Harbor, head, mouth of Washington Creek	seine	Jul 24	1	stream mouth and channel, sand, silt, clay, detritus
821	Grace Harbor, head, mouth of Grace Creek	seine	Jul 25	0.8	stream mouth and channel
822	Rainbow Cove, outlet of Lake Feldtmann	seine	Jul 25	0.6	stream mouth and channel, rock, gravel, sand, silt
823	Lake Superior, Long Point, stream mouth	seine	Jul 25	0.8	shoreline, stream mouth and channel

Appendix H, continued. Isle Royale nearshore locations sampled by Hubbs and Lagler (1949) in 1945.

Site No.	Location	Sampling method	Date, 1945	Depth (m)	Habitat Description
824	Bog pond ~30 m from L. Superior shore	seine	Jul 25	0.8	peat and detritus over gravel
825	McCormick Beach Creek	seine	Jul 25	0.5	shoreline, stream mouth and channel, bedrock, silt
826	Siskiwit Bay, outlet from Lake Halloran	seine	Jul 26	0.8	stream mouth and channel, boulders, sand, silt, detritus
827	Siskiwit Bay, stream mouth N of Senter Point	seine	Jul 26	0.8	stream mouth and channel
828	Siskiwit Bay, stream mouth SW of Senter Point	seine	Jul 26	0.25	stream mouth and channel, sand, silt, detritus
829	Siskiwit Bay, off of Senter Point	gillnet	Jul 26-27	6	open water just E of Senter Point
830	Siskiwit Bay, mouth of Big Siskiwit River	seine	Jul 26	1	stream mouth and channel, gravel, sand, detritus
832	Siskiwit Bay, ~300 m off mouth of Big Siskiwit River	trolling spoon	Jul 27	>2 ?	open water, ~0.3 km E of mouth of Big Siskiwit River
833	Siskiwit Bay, ~500 m off of Point Hay	gillnet	Jul 28	10	open water, ~0.5 km SE of Point Hay
834	Siskiwit Bay (Hay Bay), mouth of Little Siskiwit River	seine	Jul 28	0.8	channel above stream mouth, bedrock, rubble, gravel, sand
835	Siskiwit Bay (Hay Bay), mouth of Little Siskiwit River	seine	Jul 28	1	stream mouth, sand and gravel
840	Chippewa Harbor, head, stream mouth	seine	Jul 30	0.8	shoreline, stream mouth and channel, sand, silt, rock, detritus, aquatic plants
841	Chippewa Harbor, outlet from Lake Richie	seine, hook & line	Jul 30	1.5	stream mouth and channel, sand, gravel, rock, silt, detritus
842	Chippewa Harbor, outlet from Mason Lake	seine, hook & line	Jul 30	0.6	stream mouth and channel, sand, silt, detritus, aquatic plants
843	Chippewa Harbor, near mouth of Lake Richie outlet	seine?	Jul 30	?	shoreline ?
844	Chippewa Harbor, narrows below Lake Richie outlet	gillnet	Jul 30-31	10	center of harbor basin
845	Lake Superior, outlet of Lake Epidote	seine	Jul 31	0.6	shoreline and stream mouth, bedrock, boulders, silt, detritus
846	Conglomerate Bay, head, outlet from Sumner Lake	seine	Jul 31	0.5	shoreline, stream mouth and channel, sand, silt, gravel, detritus
847	Rock Harbor, Middle Islands Passage	gillnet	Jul 31 Aug 1	12	off center of harbor channel
848	Rock Harbor, SW extremity: Moskey Basin	seine	Aug 1	1	sand, silt, detritus
849	Rock Harbor, outlet from Wallace Lake	seine	Aug 1	0.8	stream mouth and channel, sand, silt, clay, detritus, boulders, bedrock
850	Rock Harbor, SW extremity: Moskey Basin, stream mouth	seine	Aug 1	0.8	stream mouth and channel, sand, silt, detritus
851	Rock Harbor, Moskey Basin, stream mouth near campground	seine	Aug 1	1	stream mouth and channel, sand silt, detritus
852	Rock Harbor, outlet from Lake Benson (Daisy Farm)	seine	Aug 1	?	stream mouth and channel